Nonlinear Environment and Economic Growth Nexus: A Panel Smooth Transition Regression Approach

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Abstract This study uses panel smooth transition regression tests to investigate the connection between carbon dioxide per capita and economic growth from 1985 to 2012. The results revealed that the nonlinear relationship switched across countries depending on the lagged GDP per capita differential during the different regimes. CO_2 emissions also responded significantly to the changes in relative oil consumption, natural gas consumption, and coal consumption. The results suggest that high-income level countries should decrease fossil-fuel use, especially oil consumption. Therefore, policy makers should implement an economic development on global climate warming to formulate relevant environmental protection.

Keywords: CO_2 Emission, Panel Smooth Transition Regression Model, Economic Growth
JEL Classification: F43

1. Introduction

The dilemma issue between economic growth and environmental protection for humans is an emerging distress. Global warming threatens the natural ecology of the Earth. An increasing number of studies have found that ecological economics have indicated the connection between environmental degradation and economic growth (Coondoo and Dinda, 2002; Soytas et al., 2007). Several studies have also evidenced that global climate warning is deeply related to the CO_2 emissions from human activities (Dinda and Coondoo, 2006; Lee and Lee, 2009; Jaunky, 2011; Al-mulali, 2012; Liddle, 2012).

The results of Jaunky (2011) revealed that economic growth has a negative impact on environmental quality. That is to say, there was a monotonically increasing relationship between income and environmental pollution. Inconsistent with previous research, Lee (2006) argued that energy consumption has a negligible effect on income. To corroborate long-term relationships among energy consumption, GDP growth, and CO_2 emissions for eight Asia-Pacific countries, Niu et al. (2011) found that increasing economic growth could probably reduce energy consumption and emissions. By employing 22 Organization for Economic Cooperation and Development (OECD) countries, Lee et al. (2008) also confirmed that energy consumption and income are more likely to have a strong long-term equilibrium relationship.

The Intergovernmental Panel on Climate Change (IPCC) reports that a likely major cause of the global warming phenomenon since 1950 is human influence (IPCC, 2013). The large increase in greenhouse gas emissions is the main cause of global warming.

Human activities are a crucial factor in influencing the climate system. The present study examines the causal relationship among CO_2 emissions, relevant energy variables, and GDP in high-income and low-income countries to address this issue.

These countries will be facing issues concerning economic growth, energy consumption, and CO_2 emissions. In particular, energy is one of the essential factors for any high-income country, and it plays an important role in economic activities. A higher level of economic development can induce more energy consumption. High-income countries must determine how they can sustain economic growth while conserving energy and decreasing emissions. On the contrary, how to accelerate economic growth while conserving energy and decreasing emissions is a prominent issue for low-income countries.

The objectives of this study are as follows: (1) to apply a nonlinear model with the threshold effect in a panel framework, called the panel smooth transition regression (PSTR) model of González et al. (2005); and (2) to explore the nonlinear relationships among CO_2 emissions, real GDP per capita, oil consumption, natural gas consumption, and coal consumption in a panel of 26 high-income countries and 12 low-income countries from the period of 1985 to 2012. This study investigates the point of regime switching in varying income levels by using GDP as a threshold variable. Given that most studies conjecture CO_2 emissions and energy use, the present study subdivides oil consumption, natural gas consumption, and coal consumption to interpret their distinct effects.

The rest of this paper is structured as follows. Section 2 presents a review of related literature. Section 3 describes the data and explains the panel methodology. Section 4 summarizes the empirical results. Section 5 presents the conclusion and proposes a number of policy implications that emerged from the study.

2. Literature Review

There is an abundance of literature exploring the relationships among CO_2 emissions, energy consumption, and economic growth using different methodologies and data sets. Dinda and Coondoo (2006) focused on income–emission relationship in 88 countries, and revealed that the short-term cointegration does not exist between CO_2 emissions and GDP per capita.

Soytas et al. (2007) applied Granger causality test and found that energy consumption directly caused carbon emissions. Zhang and Cheng (2009) examined the direction of Granger causality among economic growth, energy depletion, and CO_2 emissions in China during the period of 1960 to 2007. The result did not support that CO_2 emissions and energy consumption led to economic growth. Lotfalipour et al. (2010) indicated a unidirectional short-run Granger-cause relationship among economic growth, petroleum products, natural gas consumption, and CO_2 emissions in Iran, but no causal relationship between fuel consumption and CO_2 emissions in the long run has been found.

Numerous studies have evaluated the relationship between relevant energy consumption and GDP. Huang et al. (2008) ascertained that energy consumption and GDP based on income levels are divided into four groups. No causal relationship exists between energy depletion and economic growth for the low-income level. Dissimilar results were found in the high-income level, wherein economic growth leading to higher energy consumption indicates a negative relationship. Ozturk et al. (2010) also applied three income levels to investigate the issues of GDP and energy consumption from 1971 to 2005. First, all income group countries do not have strong Granger causality. Second, low-income countries have long-term Granger causality from GDP to energy consumption. Finally, middle-income countries have bidirectional causality. Apergis and Payne (2010) also verified that bidirectional causality exists between renewable energy depletion and economic growth in 20 OECD countries.

Existing literature on the relationship among energy depletion, economic growth, and CO_2 emissions used various methods to investigate the effect of GDP and energy depletion on CO_2 emissions. A large number of studies have appraised the empirical evidence through Granger causality and the cointegration model, which present inconclusive evidence. Examples of this line of research include Yuan et al. (2008), who proved the relationship of energy consumption (i.e. coal, oil, and electricity consumption) and economic growth in China for the period of 1963 to 2005. They found unidirectional short-run causality from GDP to coal and oil consumption, as well as long-run causality from electricity and oil consumption to GDP. Sadorsky (2009) explored the relationship between renewable energy consumption and economic growth in emerging market economies over the period of 1994 to 2003. The results indicated that positive bidirectional causality exists in the long run. The findings of Warr and Ayres (2010) provided evidence for the existence of a unidirectional causality from energy to GDP in the United States. They suggested that an increase in energy input can sufficiently stimulate output growth in the short run. GDP positively replies to increase energy and useful work input by revising to the long-term equilibrium relationship.

Recently, researchers have paid more attention to the nonlinear model. Hall et al. (2001)

pointed out that nonlinear models are more accurate in forecasting than linear models. The present paper applies the novel PSTR model developed by González et al. (2005). Chiu (2012) applied the PSTR model to examine the Environmental Kuznets Curve (EKC) for 52 developing countries from 1972 to 2003. The results advocated an EKC relationship for deforestation and the existence of a strong threshold effect between deforestation and GDP, and examined the turning points were US$3,021 and US$3,103. Duarte et al. (2013) also employed the PSTR model to analyze the relationship between water use per capita and income per capita of 65 countries over the period of 1962 to 2008. They found that the relationship between water withdrawal per person and GDP per capita is nonlinear, displaying a negative connection between GDP per capita and water withdrawal per capita.

3. Data and Econometric Methodology

This study focuses on the relationship between energy consumption and CO_2 emissions in the panel context evaluating the effect on GDP. The PSTR model developed by González et al. (2005) is a suitable approach to simultaneously settle the heterogeneity and time variability problems.

3.1 Data

The annual panel dataset of 36 countries based on income level between 1985 and 2012 is used. CO_2 emissions (metric tons per capita), oil consumption (thousand barrels daily), natural gas consumption (billion cubic feet per day), coal consumption (million tons), and GDP per capita (current US$) are obtained from the World Bank's World Development Indicators Dataset and BP Statistical Review of World Energy. All the variables are converted into their natural logarithmic form to eliminate heteroscedasticity.

3.2 PSTR model

The PSTR model is the most recent advancement of the smooth transition regression modeling of panel data with heterogeneity across panel affiliates and over time. According to González et al. (2005), the simplest PSTR model with two regimes and a single transition function can be defined as follows:

$$y_{i,t} = u_i + \beta_0' x_{i,t} + \beta_1' x_{i,t} G(z_{i,t};\gamma,c) + \varepsilon_{i,t}, \tag{1}$$

where $i = 1,\cdots\cdots,N$, $t = 1\cdots,T$. N and T denote the cross-section and time dimensions of the panel, respectively. The dependent variable $y_{i,t}$ is a scalar matrix, μ_i is the fixed individual effect, $x_{i,t}$ is a *k*-dimensional vector of time-varying exogenous variables, and $\varepsilon_{i,t}$ is the residual term. $G(z_{i,t};\gamma,c)$ is the transition function bounded between 0 and 1; it is rely on the transition variable $z_{i,t}$, which can be an exogenous variable or a conjunction of the lagged endogenous one (van Dijk et al., 2002). γ is the transition or slope parameter, defining the slope of the transition function, c is the threshold or location parameter, and the both parameters are endogenously estimated.

According to Teräsvirta (1994), the transition function can be described as follows:

$$G(z_{i,t};\gamma,c) = \left[1+\exp\left(-\gamma\Pi_{j=1}^{m}(z_{i,t}-c_j)\right)\right]^{-1}, \tag{2}$$

where $\gamma > 0$, $c = (c_1,\ldots,c_m)'$, and m is the number of location or threshold parameters. The slope parameter γ settles the smoothness of the transitions. In practice, considering $m = 1$ or $m = 2$ is usually sufficient because these values permit of commonly encountered types of variations in the parameters. In cases where $m = 1$, the model implies that the two extreme regimes are connected with the low and high values of $q_{i,t}$ with a single monotonic transition of the coefficients from β_0 to $\beta_0 + \beta_1$ as $z_{i,t}$ increases, where the change is centered around c_1. For $m = 2$, the transition function takes a value of 1 for both the low and high values of $z_{i,t}$, minimizing at $(c_1 + c_2)/2$. In this case, if $\gamma \rightarrow \infty$, the model transforms into a three-regime threshold model. If $\gamma \rightarrow 0$, the transition function will reduce into a homogenous or linear fixed effect panel regression for any value of m.

A generalization of the PSTR model admits more than two different regimes. The PSTR model can be formulated as follows:

$$y_{i,t} = u_i + \beta_0' x_{i,t} + \sum_{j=1}^{r} \beta_j' x_{i,t} G_j(z_{i,t};\gamma_j,c_j) + \varepsilon_{i,t}, \tag{3}$$

where the $G_j(z_{i,t};\gamma_j,c_j)$, $j = 1,\cdots y$, are the transition functions.

3.3 Building Model of CO_2 Emission

According to the IPCC[1] report, the biggest cause of global warming is fossil-fuel use (IPCC, 2007)[2]. Thus, the PSTR specification of CO_2 emissions with $\gamma + 1$ regimes is as follows:

$$CO2_{i,t} = u_i + \theta_1 oil_{i,t} + \theta_2 gas_{i,t} + \theta_3 coal_{i,t}$$
$$+ \sum_{j=1}^{r}\left(\theta_1' oil_{i,t} + \theta_2' gas_{i,t} + \theta_3' coal_{i,t}\right) G_j(gdp_{i,t-d};\gamma_j,c_j) + \varepsilon_{i,t}, \tag{4}$$

where $CO_{2i,t}$ denotes the CO_2 emissions of high-income and low-income levels, $oil_{i,t}$ is oil consumption, $gas_{i,t}$ is natural gas consumption, $coal_{i,t}$ is coal consumption, $Gdp_{i,t-d}$, $d = 0,1,2,3,$ is the lagged GDP, μ_i is a time-invariant individual effect, and $\varepsilon_{i,t}$ is a residual term. $G_j(gdp_{i,t-d};\gamma_j,c_j)$ is again the transition function that describes the smooth-switching process of CO_2 emissions. In contrast to the specification of the transition function in González et al. (2005), this paper replaced $gdp_{i,t}$ with $gdp_{i,t-d}$, implying that a lagged effect of the transition variable on CO_2 emissions might exist. The optimal lag length of the GDP is determined by the minimum Akaike information criterion (AIC) and Bayesian information (BIC). This specification is especially important for adopting specific EKC[3] variables as the transition variable because of the existence of lagged effects from EKC.

In the case of two extreme regimes (i.e., r + 1 = 2) and a single transition function, the marginal effects of oil consumption, natural gas consumption, and coal consumption on CO_2 emissions are equal to $\theta_k + \theta'_k G_1(gdp_{i,t-d};\gamma_1, c_1)$ for k = 1, 2, 3, respectively. This condition means that the marginal effects can be defined as a weighted average of parameters θ_k and θ'_k, which can be different from the estimated parameters for extreme regimes (i.e., θ_k and θ'_k). Therefore, the direct interpretation of the values of these parameters is generally difficult. Interpreting (1) the sign of these parameters, which indicates an increase or a decrease in the marginal effects of economic determinants on CO_2 emissions according to the value of the threshold variable, and (2) the varying coefficient in the time and individual dimensions is generally preferable.

3.4 Estimation Procedure

Following González et al. (2005), this study adopts a three-step procedure to estimate our constructed model of CO_2 emissions. First, we test the linearity against the smooth transition models. Second, when the null hypothesis (linearity) is rejected, we determine the number of transition functions by leading tests of no remaining nonlinearity. Finally, we remove the individual effects and then utilize nonlinear least squares to the transformed model.

Selecting the specifications of the transition variable and the decision of the regime number entails major problems. The transition variable plays a pivotal position in influencing the effects of independent variables on the dependent variable. This paper takes into account the Environmental Kuznets Curve (EKC) hypothesis as the transition variable. According to Fouquau et al. (2008), it consists of approximating the transition function $G_j(z_{i,t-d};\gamma_j, c_j)$ applying the first and second Taylor expansions around $\gamma = 0$ to test the linearity. An equivalent hypothesis in an auxiliary regression is then tested.

$$CO_{2i,t} = \pi_i + \pi_1 oil_{i,t} + \pi_2 gas_{i,t} + \pi_3 coal_{i,t} \\ + \pi'_1 oil_{i,t} gdp_{i,t-d} + \pi'_2 gas_{i,t} gdp_{i,t-d} + \pi'_3 coal_{i,t} gdp_{i,t-d} + \eta_{i,t}, \tag{5}$$

where π_i is the intercept; π and π' are estimated parameters to the slope parameter of transition function, testing the linearity of environment and economic growth model; $\eta_{i,t}$ is the disturbance term.

Testing linearity is equivalent to testing $H_0 : \pi_1' = \pi_2' = \pi_3' = 0$. When the linearity is rejected, the methodology of the sequential tests is applied to test the H_0 of no remaining nonlinearity. The testing procedure works as follows. First, a linear model is tested against a model with one threshold. If the null hypothesis is rejected, the one-threshold model is tested against at least two-threshold models. The measure continues until the hypothesis of no extra threshold is supported. SSR_0 indicates the sum of the squared residuals under H_0 (linear panel model with individual fixed effects) and SSR_1 means the sum of squared residuals under H_1 (PSTR model with two extreme regimes), then the F statistic calculates the following:

$$LM_F = \left[\left(SSR_0 - SSR_1\right)/k\right]/\left[SSR_0/\left(TN - N - K\right)\right], \tag{6}$$

where k is the number of explanatory variables. Under the null hypothesis, the LM statistic becomes an asymptotic $x^2(k)$ distribution.

4. Data Analysis and Result Interpretation

4.1 Results of Panel Unit Root Tests

Considering the efficiency, Levin et al. (2002) indicated that the panel-based unit root test is superior to that of unit root test based on individual time. Table 1 presents the results of the panel unit root tests for all the variables. The results show that most of the income-level values reject the null hypothesis, implying that the time series variables in this study are I (0).

4.2 Results of Linearity Test

First, this paper examines a linear model and tests it against a nonlinear model with one threshold. The null hypothesis of the linear model is rejected (Table 2). This finding indicates the existence of a nonlinear relationship between CO_2 emissions and real GDP per capita with different transition variables [i.e., the (lagged) GDP differentials, $gdp_{i,t-d}$, $d = 0,1,2,3$] for high-income and low-income levels. The results imply the following conditions: (1) Their CO_2 emissions have a nonlinear dynamic process for any income level. (2) CO_2 emissions and their determinants, including relative real GDP per capita, oil consumption, natural gas consumption, and coal consumption are nonlinear. (3) Adopting a nonlinear model to examine the CO_2 emissions is an adequate approach.

4.3 Results of Parameter Constancy Test and Determining the Number of Regimes

Following these linearity tests, this paper applies a sequence of LM tests to check whether the order m is 1 or not. The F statistics of the LM test has better size properties in small samples than the x^2 statistics (van Dijk et al., 2002). As such, this paper determines the number of transition functions with the F-version LM test (LM_F). The results of no remaining nonlinearity testing and the number of transition functions are shown in Table 3 based on the auxiliary equation (5). The results imply no remaining nonlinearity. For the high-income level, when the number of location parameters is appointed to be 1 ($m=1$), the optimal number of transition functions at all specified transition variables ($gdp_{i,t-d} \equiv 0, 1, 2$) is also 1 ($\gamma = 1$). However, when $m=2$, the optimal number of transition functions for $gdp_{i,t-d} = 1, 2$ is 1 (i.e., $\gamma = 2$) and that for $gdp_{i,t-d} = 0$ is 2 (i.e., $\gamma = 2$). Nevertheless, whether the order m is 1 or 2, the optimal number of transition functions at all specified transition variables ($gdp = 0, 1, 2, 3$) is 2 ($\gamma = 2$) for the low-income level. In particular, if current and lagged GDP differentials are used as the transition variable in the PSTR model, the optimal number of the transition functions will be different.

4.4 Results of Parameter Estimate

The parameter estimation results of PSTR model are shown in Table 4 based on the equation (4). The parameters' estimates are observed that there are the relationships among each other. A positive sign (a negative sign) of the parameters θ_i and $\theta_i^{'}$ means that an increase of the transition variable for testing the linearity based on equation (5) involves an increase (decrease) of the environment–growth coefficient. Firstly, this paper uses the AIC and BIC to decide which one is the optimal estimation model for evaluating the behavior of CO_2 emissions. The results show one transition function ($\gamma = 1$) with one threshold ($m=1$), and the lagged two periods of the transition variable ($gdp_{i,t-2}$) is optimal for all samples. The results imply that the logistic transition function is the optimal one, not the exponential transition function. In particular, the CO_2 emissions illustrate an asymmetrical nonlinear adjustment process. The coefficients for the threshold variable ($gdp_{i,t-2}$) are also positive and significant for both regimes, except for the coefficient of coal consumption for the high regime. The results are similar to those of Ozturk et al. (2010) and Zhang and Cheng (2009). The effect of oil consumption is highest for the high-income level, whereas the effect of coal consumption is the highest for the low-income level. The results show that different countries have different energy depletion schemes and various sources of energy (Soytas and Sari, 2007).

For the high-income level, the threshold value c and transition parameter γ are 9.8371 and 3.6547, respectively. The results yield a threshold at a GDP per capita of $18715.36, which divides the sample into two regimes. The effects of relative oil consumption, natural gas consumption, and coal consumption on CO_2 emissions are significantly positive at $(0.5984+0.0354*G(gdp_{i,t-2};\ 3.6547,\ 9.8371)>0)$, $(0.0541+0.0907*G(gdp_{i,t-2};\ 3.6547,\ 9.8371)>0$, $(0.2682-0.1027*G(gdp_{i,t-2};\ 3.6547,\ 9.8371)>0$, respectively, depending on a two-period lag of real GDP per capita differential in different regimes (i.e., the threshold value is 9.8371). The effects of oil consumption on CO_2 emissions increase in the low regime, whereas the effects of natural gas consumption increase in the high regime. In two extreme cases, $(G(gdp_{i,t-2};\ 3.6547,\ 9.8371)=0$ and $(G(gdp_{i,t-2};\ 3.6547,\ 9.8371)=1$, the effects of oil consumption, natural gas consumption, and coal consumption are (0.5894 and 0.6248), (0.0541 and 0.1448), (0.2682 and 0.1655), respectively.

For the low-income level, the threshold value c and transition parameter γ are 6.0488 and 19.6329, respectively. The result yields a threshold at a GDP per capita of $423.60, which divides the sample into two regimes. The effects of relative oil consumption, natural gas consumption, and coal consumption on CO2 emissions are significantly positive at $(0.2117+0.074*G(gdp_{i,t-2};\ 19.6329,\ 6.0488)>0)$, $(0.0541+0.0907*G(gdp_{i,t-2};\ 19.6329,\ 6.0488)>0)$, and $(0.2682-0.1027*G(gdp_{i,t-2};\ 19.6329,\ 6.0488)>0)$, respectively, depending on a two-period lag of real GDP per capita differential in different regimes (i.e., the threshold value is 6.0488). The effects of oil consumption on CO_2 emissions increase in the low regime, whereas the effects of natural gas consumption increase similarly in the two regimes. In two extreme cases, the effects are 0.2117 and 0.6248, respectively.

5. Conclusion

This paper re-examines the pollution–income path based on a unique methodology. The smooth transition between regimes is developed to estimate a regime switch. The use of the PSTR model in this study emphasizes the existence of a smooth nonlinear relationship (threshold effect) between CO_2 emissions and oil consumption, natural gas consumption, and coal consumption on the income level. This paper considers the EKC variable (i.e., the lagged GDP per capita differential) as the threshold variable, which can control other factors associated with CO_2 emissions and can potentially explain the heterogeneity in the panel data model between relative energy consumption and CO_2 emissions. The results revealed that a significant positive correlation exists among CO_2 emissions, oil consumption, natural gas consumption, and coal consumption.

The contribution of this paper not only expands existing literature, but also merits special attention to CO_2 emissions and energy consumption on the income level. Different countries have different energy consumption patterns and various sources of energy. This work also cautions policy makers when considering energy conservation and implementation of energy-saving policies, where energy efficiency has to avoid the rebound effect[4]. Our main results can be summed up as follows. First, this paper verifies the significant nonlinearity between CO_2 emissions and energy consumption, including relative oil consumption, natural gas consumption, and coal consumption on CO_2 emissions. Second, the lagged two periods of GDP differentials influence the marginal effects of energy consumption on CO_2 emissions. The estimated coefficients of energy consumption are also allowed to vary according to different observable lagged two periods of GDP differentials. Third, GDP differentials nonlinearly Granger-cause changes in CO_2 emissions, implying that current economic growth can nonlinearly influence future CO_2 emissions. Fourth, the PSTR specification considers that the effect of oil consumption is pronounced for the high-income level and the effect of coal consumption is crucial for the low-income level. Finally, the results suggest that policy makers not only consider encouraging economic development, but also have a duty to promote energy conservation and decrease CO_2 emissions.

Endnotes

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1. IPCC was established in 1988 by the World Meteorological Organization and the United Nations Environment Programme to assess scientific-, technical-, and human-induced climate change, along with its potential impact and options for mitigation and adoption. IPCC consists of three working groups (i.e., WGI, WG II, and WGIII) that comprise some of the leading scientists from around the globe.
2. IPCC AR4 WG2 (2007), Parry, M.L.; Canziani, O.F.; Palutikof, J.P.; van der Linden, P.J.; and Hanson, C.E., ed., Climate Change 2007: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press.
3. EKC hypothesizes that the relationship between per capita income and the use of natural resources and/or the emission of wastes has an inverted U-shape.
4. The rebound effect is the term used to describe the effect of lower costs of energy services because of increased energy efficiency on consumer behavior, both individually and nationally (http://www.eoearth.org).

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Table 1. Panel Unit Root Test Results

Variables	High-Income Level	Low-Income Level
$lnCO_2$	-5.78199*** (0.0000)	-3.60006*** (0.0002)
lnGDP	-3.17760*** (0.0007)	-8.37569*** (0.0000)
lnOIL	-3.30436*** (0.0005)	-4.22233*** (0.0000)
lnGAS	-8.29495*** (0.0000)	-1.70154** (0.0444)
lnCOAL	-1.46408* (0.0716)	-1.31755* (0.0938)

Notes: *, **, *** represent significance at 10%, 5% and 1% levels, respectively.

Table 2. Linearity Test

Level		Testing statistic	Number of location parameters (m)			
			m=1		m=2	
High-income	d=0	LM	176.626	(0.000)	202.742	(0.000)
		LMF	76.659	(0.000)	46.229	(0.000)
		LRT	204.924	(0.000)	241.319	(0.000)
	d=1	LM	165.746	(0.000)	195.075	(0.000)
		LMF	71.144	(0.000)	44.362	(0.000)
		LRT	191.433	(0.000)	232.091	(0.000)
	d=2	LM	142.272	(0.000)	176.768	(0.000)
		LMF	58.772	(0.000)	39.13	(0.000)
		LRT	161.473	(0.000)	207.837	(0.000)
Low-income	d=0	LM	21.070	(0.000)	141.726	(0.000)
		LMF	7.159	(0.000)	38.664	(0.000)
		LRT	21.759	(0.000)	184.074	(0.000)
	d=1	LM	18.482	(0.000)	147.098	(0.000)
		LMF	6.231	(0.000)	42.408	(0.000)
		LRT	19.03	(0.000)	196.067	(0.000)
	d=2	LM	33.919	(0.000)	137.805	(0.000)
		LMF	12.075	(0.000)	37.764	(0.000)
		LRT	35.908	(0.000)	181.842	(0.000)
	d=3	LM	8.902	(0.000)	138.942	(0.000)
		LMF	2.905	(0.000)	40.546	(0.000)
		LRT	9.037	(0.000)	186.606	(0.000)

Note: 1. H_0: Linear Model against H_1: PSTR model with at least one Threshold Variable.
2. LM, LM_F, and LRT denote the statistics of the Wald test, F-version LM test, and likelihood ratio test, respectively.

Table 3. Tests for Remaining Nonlinearity

Transition	$GDP_{i,t}$	
Number of location parameters (m)	m=1	m=2
High-income	LM_F	LM_F
d=0	3.026** (0.029)	7.802*** (0.000)
d=1	1.709 (0.164)	6.212*** (0.000)
d=2	1.866 (0.131)	3.186*** (0.004)
Low-income	LM_F	LM_F
d=0	13.081*** (0.00)	23.429*** (0.000)
d=1	15.807*** (0.000)	26.878*** (0.000)
d=2	15.741*** (0.000)	22.367*** (0.000)
d=3	19.102*** (0.000)	24.225*** (0.000)
d=4	15.460*** (0.000)	21.688*** (0.000)

Notes: H_0: PSTR with r = 1 against H_1: PSTR with at least r = 2.

Tabel 4. Estimation Results of CO_2 Emission -The PSTR Specification

High-income	d=0	d=1	d=2
	r=m=1	r=m=1	r=m=1
γ	3.6687	3.5858	3.6547
c	9.9042	9.8507	9.8371
θ_1	0.5788*** (37.9604)	0.5831*** (38.0111)	0.5894*** (40.7759)
θ_1'	0.0365*** (10.2004)	0.0358*** (9.8967)	0.0354*** (10.4361)
θ_2	0.047*** (6.8844)	0.0493*** (6.1662)	0.0541*** (5.9997)
θ_2'	0.0877*** (11.2689)	0.0902*** (12.1604)	0.0907*** (12.9085)
θ_3	0.2622*** (21.4136)	0.2662*** (21.1900)	0.2682*** (21.8373)
θ_3'	-0.1000*** (-10.4078)	-0.1005*** (-10.6331)	-0.1027*** (-11.2336)
AIC	-6.5599	-6.6365	-6.7041
BIC	-6.5062	-6.5812	-6.6472
Threshold value	20014.25	18971.63	18715.36
Low-income	d=0#	d=1#	d=2#
	r=m=1	r=m=1	r=m=1
γ	18.1754	12.6302	19.6329
c	6.0524	6.0194	6.0488
θ_1	0.224*** (8.3754)	0.2037*** (8.5893)	0.2117*** (8.3210)
θ_1'	0.0785*** (15.0478)	0.0848*** (13.2878)	0.0740*** (12.2005)
θ_2	0.0582*** (5.6335)	0.068*** (7.4705)	0.0726*** (6.9933)
θ_2'	0.0542*** (3.6198)	0.0550*** (3.2301)	0.0629*** (2.8676)
θ_3	0.425*** (23.9470)	0.4339*** (22.8775)	0.4274*** (19.4288)
θ_3'	-0.0868*** (-12.7783)	-0.0948*** (-11.6979)	-0.0859*** (-11.257)
AIC	-4.9810	-5.0891	-5.2157
BIC	-4.8901	-4.9957	-5.1197
Threshold value	425.132	411.33	423.60

Notes: **represents significance at 5% levels. #: one of the estimated threshold values are the estimated coefficients of the oil consumption, natural gas consumption, and coal consumption, in regime 1 and regime 2, respectively ($\gamma = m = 2$). The digits in brackets are the t-statistics.