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The Richer the Greener: Evidence from G7 Countries

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Abstract

This research applies a recently-developed nonlinear panel smooth transition regression (PSTR) model and takes into account the potential endogeneity biases to examine whether Environmental Kuznets Curve (EKC) exists in G7 countries over the period 1991-2008. This research makes three contributions to the CO_2 emissions literature. First, we apply the panel smooth transition regression (PSTR) model of González et al. (2005) to investigate the relationship among CO_2 emissions per capita, energy use per capita, real gross fixed capital formation, real GDP per capita, and labor participation rate for G7 countries. Second, we complement the existing literature by simultaneously examining the impacts of energy use, real gross fixed capital formation, real GDP, and labor participation rate on CO_2 emissions and take into account endogenous determination of real GDP on the PSTR model for CO_2 emissions. Third, based on the characteristics of the PSTR model, we can consider the elasticity of CO_2 emissions changes with country and time to analyze the elasticity of heterogeneous countries and the potential impacts of structural breaks on the CO_2 emissions elasticity in the panel framework. Based on the elasticity of the CO_2 emissions with respect to real income per capita, the environmental quality is a necessary good in Japan, the UK, and the USA, but a luxury good in the rest of G7 countries. Thus, there exists an inverted U-shaped relationship between CO_2 emissions and real income per capita with the threshold value of US$20,488, which is endogenously determined. This finding supports the existence of EKC in G7 countries. In other words, our results confirm there exists the regime-switching effect of real income on CO_2 emissions in G7 countries.

Keywords: environmental Kuznets curve, CO_2 emissions, energy use, real gross fixed capital formation, real income per capita, Labor participation rate, panel smooth transition regression model, G7 countries

1. Introduction

The previous study of Ang (2007) examined the nexus between emissions, energy consumption, and real GDP for France over the period of 1960-2000. The empirical results provided evidence for a strongly long-run relationship between these variables. In terms of causality, the findings indicated that GDP causes both energy use and emissions in the long-run, while a unidirectional causality running from energy use to GDP is detected in the short-run. The finding estimates of Apergis and Payne (2009, 2010) showed that real GDP exhibits the inverted U-shape pattern associated with the EKC hypothesis, and energy consumption showed a positive and statistically significant impact on emissions. Acaravci and Ozturk (2010) explored the causal relationship between CO2 emissions, real GDP, and energy consumption for selected European (19) countries over the period of 1960-2005. Their empirical findings demonstrated the validity of EKC hypothesis only for Denmark and Italy. The findings of Lean and Smyth (2010) concluded a significant positive long-run elasticity estimate of emissions with respect to electricity consumption and supported the validity of EKC hypothesis for five ASEAN countries over the period of 1980-2006.

The Environmental Kuznets Curve (hereafter, EKC) hypothesis postulates an inverted U-shaped relationship between different pollutants and income per capita, in other words, environmental pollution increases up to a certain level as income rises; afterwards, it decreases. A various literature on EKC has grown in recent years. The common point of all the studies is the declaration that the environmental quality worsens at the early stages of economic growth and subsequently improves at the later stages. In another word, environmental pressure increases faster than income at early stages of economic growth and slows down relative to GDP growth at higher income levels.

Early in the economic development process individuals are unwilling to trade consumption for investment in environmental protection; as a result environmental quality declines. Once individuals reach a given level of consumption, known in the EKC literature as the income "turning point", they begin to demand increasing investments in an improved environment. Thus after the turning point, environmental quality indicators begin to demonstrate decreases in pollution and environmental degradation. In March 2007, the European Council committed to reducing greenhouse gas emissions by at least 20% from the level in 1990. Since the greenhouse effect and the reduction of pollution emissions are global concerns, one needs to clarify the link among CO_2 emissions per capita, energy use per capita, real gross fixed capital formation, real GDP per capita, and labor participation rate in the present study.

The paper aims to make the following contributions to the CO_2 emissions literature. First, we apply the panel smooth transition regression (PSTR) model of González *et al*. (2005) to investigate the relationship among CO_2 emissions per capita, energy use per capita, real gross fixed capital formation, real GDP per capita, and labor participation rate for G7 countries over the period 1991-2008. This choice is justified by two main reasons. Firstly, the fact that per capita GDP elasticity of CO_2 emissions depends on income level, clearly corresponds to the definition of a threshold regression model. Secondly, we justify this methodology by showing that the quadratic polynomial model widely used to examine the CO_2 elasticity can be viewed as an approximation of the PSTR model (Fouquau et al., 2009).

Second, most studies in the literature focus only on analyzing the elasticity of CO_2 emissions with respect to real GDP, but they seldom consider the impact of energy use, real gross fixed capital formation, real income, and labor participation rate on CO_2 emissions simultaneously. We complement the existing literature by simultaneously examining the impacts of energy use, real gross fixed capital formation, real GDP, and labor participation rate on CO_2 emissions and take into account endogenous determination of real GDP on the PSTR model for CO_2 emissions.

Third, based on the characteristics of the PSTR model, we can consider the elasticity of CO_2 emissions changes with country and time to analyze the elasticity of heterogeneous countries and the potential impacts of structural breaks (parameter instability) on the CO_2 emissions elasticity in the panel framework. The structural breaks are a common problem in macroeconomic series when they are usually affected by exogenous shocks or regime changes in environmental or economic events, i.e., economic development, energy crisis, global warming, the Kyoto Protocol, renewable energy technology, and so on (Lee & Chang, 2007; Lee & Lee, 2009).

The rest of paper is structured as follows. Section 2 demonstrates the data and variables; Section 3 introduces the econometric methodology of panel smooth transition regression model while Section 4 reports the empirical results. Section 5 offers some conclusions.

2. Data and Variables

We use a balanced panel of G7 countries observed for the years 1991–2008 from the World Development Indicators (WDI) database of World Bank. G7 countries include Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States. The reason why we choose G7 as our empirical sample is that these countries have experienced a completed economic development process. Thus, we can observe the tradeoff between economic growth and environmental quality across the different stages of economic development process.

We define all the variables in this study as follows: $CO2_{it}$ presents CO_2 emissions (metric tons per capita); GDP_{it} is real GDP per capita (constant 2000 US$). EU_{it} is energy use per capita (kg of oil equivalent per capita); $GFCF_{it}$ is real gross fixed capital formation (constant 2000 US$M); LP_{it} is labor participation rate, total (% of total population ages 15+).

Table 1A and Table 1B show all variables cross-sectional statistics for each country and longitudinal statistics for each year. From Table 1A, we find that the United States and France have the highest and lowest means of CO_2 emissions, with values of 19.24 and 6.37 metric tons per capita, respectively. Japan and Italy have the highest and lowest means of GDP per capita at US$39,946 and US$18,724. Interesting is that we find Canada and Italy have the highest and lowest means of energy use, with values of 7,976 and 2,902 kg of oil equivalent per capita. The United States and Canada have the highest and lowest means of gross fixed capital formation at 2000 US$ of US$1,717,729M and US$140,136M, respectively. Finally, means of labor participation rates are top at 66.02% in the United States and bottom at 48.16% in Italy. From Table 1B, we found that the means of CO_2 emissions have the highest and the lowest at 11.63 and 10.74 metric tons per capita in 1991 and 2008. The means of real GDP per capita ranged from US$22,362 in 1991 to US$29,212 in 2007. The means of energy use peaked at 5,091 in 2004 and plunged to 4,755 in 1992. The means of gross fixed capital formation ranged between a maximum of US$696,363M in 2007 and a minimum of US$474,142M in 1991. The highest and the lowest means of labor participation are 60.36% in 1991 and 59.27% in 1995.

Table 1A. Cross-sectional descriptive statistics for each country

Variables	Statistics	Canada	France	Germany	Italy	Japan	United Kingdom	United States
CO2 emissions (metric tons per capita)	mean	16.47	6.37	10.54	7.73	9.45	9.38	19.24
	maximum	17.47	7.32	12.01	8.13	9.86	10.34	20.18
	minimum	15.61	5.86	9.57	7.25	8.88	8.52	17.94
	StdDev	0.66	0.38	0.73	0.24	0.28	0.51	0.61
Energy use (kg of oil equivalent per capita)	mean	7,976	4,134	4,149	2,902	3,949	3,700	7,783
	maximum	8,424	4,313	4,306	3,137	4,090	3,878	8,057
	minimum	7,389	3,843	4,033	2,578	3,583	3,390	7,481
	StdDev	284	129	68	188	157	118	123
Gross fixed capital formation (constant 2000 US$M)	mean	140,136	239,459	375,639	218,649	1,179,788	241,726	1,717,729
	maximum	207,568	307,072	420,852	257,999	1,279,200	336,543	2,247,323
	minimum	95,442	192,279	347,119	176,483	1,101,119	168,053	1,012,231
	StdDev	38,379	38,924	22,264	26,811	57,415	56,457	422,529
GDP per capita (constant 2000 US$)	mean	22,593	21,149	22,503	18,724	36,946	24,312	33,665
	maximum	26,230	23,585	25,620	20,291	40,707	29,628	38,744
	minimum	18,827	18,858	20,344	16,818	34,605	19,009	27,826
	StdDev	2,678	1,688	1,633	1,237	1,918	3,747	3,740
Labor participation rate, total (% of total population ages 15+)	mean	65.73	55.36	58.58	48.16	62.32	61.43	66.02
	maximum	67.30	56.30	59.80	50.10	64.10	62.20	66.80
	minimum	64.20	54.80	57.60	46.90	60.40	60.80	65.40
	StdDev	1.08	0.56	0.64	0.93	1.44	0.47	0.50

Table 1B. Longitudinal descriptive statistics for each year

Variables	Statistics	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
CO2 emissions (metric tons per capita)	mean	11.63	11.51	11.49	11.31	11.41	11.55	11.46	11.39	11.13	11.40	11.31	11.16	11.37	11.38	11.30	11.10	10.95	10.74
	maximum	19.25	19.01	19.88	19.87	19.67	19.84	20.18	19.75	19.81	19.54	18.91	18.89	18.85	18.99	18.92	18.47	18.51	17.94
	minimum	7.32	6.76	6.60	6.24	6.62	6.84	6.33	6.80	6.15	6.02	6.30	6.17	6.24	6.23	6.22	6.03	5.86	5.87
	Std Dev	4.48	4.57	4.93	4.83	4.65	4.68	4.94	4.70	4.84	5.07	4.74	4.73	4.82	4.84	4.86	4.67	4.70	4.58
Energy use (kg of oil equivalent per capita)	mean	4,759	4,755	4,784	4,814	4,888	4,993	4,958	4,951	4,991	5,052	5,014	4,972	5,042	5,091	5,082	5,006	4,953	4,848
	maximum	7,632	7,677	7,710	7,835	7,862	7,957	7,966	7,838	8,011	8,172	7,975	7,915	8,272	8,364	8,424	8,224	8,248	8,001
	minimum	2,646	2,627	2,612	2,578	2,799	2,796	2,834	2,913	2,957	3,012	3,021	3,016	3,115	3,128	3,137	3,090	3,016	2,943
	Std Dev	1,951	1,991	2,035	2,095	2,045	2,045	2,059	2,006	2,072	2,128	2,015	2,024	2,080	2,110	2,124	2,059	2,123	2,026
Gross fixed capital formation (constant 2000 US$M)	mean	474,142	478,568	476,979	492,289	507,493	533,688	557,346	575,991	605,356	632,955	629,877	611,931	621,199	646,419	673,066	692,730	696,363	670,218
	maximum	1,279,200	1,250,684	1,217,063	1,233,212	1,310,483	1,421,421	1,546,596	1,699,527	1,854,966	1,982,200	1,960,711	1,901,795	1,962,412	2,084,632	2,195,928	2,247,323	2,212,314	2,084,363
	minimum	100,147	97,403	95,442	102,580	100,407	104,806	120,753	123,696	132,665	138,894	144,415	146,669	155,769	167,863	183,505	196,454	203,409	207,568
	Std Dev	470,976	474,447	486,321	500,695	520,779	559,943	588,754	611,106	653,109	691,214	681,205	654,606	672,635	711,636	749,201	760,478	741,092	694,687
GDP per capita (constant 2000 US$)	mean	22,362	22,534	22,578	23,098	23,521	23,907	24,532	24,948	25,539	26,382	26,639	26,842	27,103	27,666	28,078	28,667	29,212	28,970
	maximum	34,605	34,801	34,775	34,956	35,478	36,321	36,792	35,947	35,828	36,789	36,776	36,787	37,227	38,236	38,972	39,772	40,707	40,254
	minimum	16,854	16,973	16,818	17,176	17,671	17,867	18,191	18,449	18,713	19,388	19,737	19,764	19,601	19,745	19,782	20,102	20,291	19,903
	Std Dev	6,443	6,547	6,611	6,564	6,591	6,879	6,955	6,682	6,647	6,771	6,630	6,650	6,898	7,217	7,483	7,592	7,731	7,616
Labor participation rate, total (% of total population ages 15+)	mean	60.36	59.91	59.57	59.47	59.27	59.33	59.43	59.49	59.60	59.56	59.37	59.51	59.69	59.61	59.74	59.87	59.94	60.09
	maximum	66.30	65.90	65.80	66.10	66.20	66.40	66.70	66.70	66.70	66.80	66.40	66.40	67.10	67.00	66.70	66.70	67.10	67.30
	minimum	50.10	48.30	47.80	47.30	46.90	47.00	47.00	47.30	47.60	47.60	47.80	48.30	48.70	49.40	48.90	49.00	48.70	49.10
	Std Dev	6.00	6.41	6.47	6.62	6.69	6.64	6.76	6.67	6.56	6.59	6.47	6.38	6.24	5.96	6.00	6.02	6.14	6.06

3. Methodology

3.1 Specification

The PSTR model is the most recent extension of smooth transition regression (STR) modeling to panel data with heterogeneity across the panel members and over time. In this study, we utilize the simplest PSTR model with two extreme regimes and a single transition function defined as follows:

$$y_{it} = \alpha_i + \beta_0 x_{it} + \beta_1 x_{it} g(q_{it};\gamma,c) + \varepsilon_{it}. \tag{1}$$

where $i = 1,......., N$, $t = 1,........, T$, and N and T stand for the cross-section and time dimensions of the panel and y_{it} is log-transformed CO_2 emissions (metric tons per capita); α_i is the fixed individual effect; x_{it} is a k-dimensional vector of time-varying exogenous variables, including $LGDP_{it}$, log-transformed GDP per capita (constant 2000 US$); LEU_{it}, log-transformed energy use (kg of oil equivalent per capita); $LGFCF_{it}$, log-transformed gross fixed capital formation (constant 2000 US$); LP_{it}, labor participation rate, total (% of total population ages 15+); β_0 and β_1 are the parameters of exogenous variables; ε_{it} is the residual term. The transition function $g(q_{it};\gamma,c)$ is a continuous function of the observable variable q_{it}. The transition function is normalized to be bounded between 0 and 1. We assume that the transition function $g(q_{it};\gamma,c)$ follows a logistic function:

$$g(q_{it};\gamma,c)=\left(1+\exp\left(-\gamma\ (q_{it}-c)\right)\right)^{-1} \quad with \quad \gamma>0 \tag{2}$$

When $\gamma \to \infty$, the transition function $g(q_{it};\gamma,c)$ tends to be an indicator function. When $\gamma \to 0$, the transition function $g(q_{it};\gamma,c)$ becomes constant and the model collapses into a homogenous or linear panel regression model with fixed effects (so-called "within" model). To investigate the real GDP per capita sensitivity of CO_2 emissions per capita, we have to utilize $LGDP_{it}$ as the transition variable in this study. Consequently, this specification allows for an evaluation of the influence of the variable $LGDP_{it}$ on CO_2 emissions according to the level of $LGDP_{it}$.

To differentiate both side of the Eq. (1) with respect to $LGDP_{it}$, LEU_{it}, $LGFCF_{it}$ and LP_{it}, and then the combined coefficients of $LGDP_{it}$, LEU_{it}, $LGFCF_{it}$ and LP_{it} for ith country at time t are defined as a weighted average of parameters (a_1, a_2), (b_1, b_2), (c_1, c_2), and (d_1, d_2), respectively, as follows:

$$e_{it}^{LGDP}=\frac{\partial LCO2_{it}}{\partial LGDP_{it}}=a_1+a_2 g(LGDP_{it};\gamma,c)+a_2 LGDP_{it} g'(LGDP_{it};\gamma,c) \tag{3}$$

$$e_{it}^{LEU}=\frac{\partial LCO2_{it}}{\partial LEU_{it}}=b_1+b_2 g(LGDP_{it};\gamma,c) \tag{4}$$

$$e_{it}^{LGFCF}=\frac{\partial LCO2_{it}}{\partial LGFCF_{it}}=c_1+c_2 g(LGDP_{it};\gamma,c) \tag{5}$$

$$e_{it}^{LP}=\frac{\partial LCO2_{it}}{\partial LP_{it}}=d_1+d_2 g(LGDP_{it};\gamma,c) \tag{6}$$

Here, e_{it}^{LGDP}, e_{it}^{LEU}, e_{it}^{LGFCF}, and e_{it}^{LP} present the estimated CO_2 emissions elasticity with respect to real GDP, energy use, gross fixed capital formation, and labor participation rate, respectively, which vary over time and across countries. Parameters a1, b1, c1, and d1 are the traditional linear model's elastic values. The sign of a2, b2, c2, and d2 indicates an increase or a decrease in the coefficient depending on the value of the real GDP and varying coefficient over time and across countries given by Eq. (3) to Eq. (6).

3.2 Estimation and Linearity Test

The estimation of the PSTR model consists of several stages. In the first step, a linearity test is applied and the threshold specification with one transition function is estimated. Then, if the linear specification is rejected, the optimal number of transition functions is determined by conducting tests of no remaining non-linearity.

The estimation of the parameters of the PSTR model consists of eliminating the individual effects α_i by removing individual-specific means and then by applying nonlinear least squares to the transformed model (González et al., 2005). This method is equivalent to the maximum likelihood estimation in the case of normal errors. However, before estimating the PSTR model, it is necessary to determine whether the regime-switching effect is statistically significant. Testing the linearity can be done by H_0: $\gamma=0$ or H_0: $\beta_0=\beta_1$ in Eq. (1). But in both cases, the test will be nonstandard since, under H_0 the PSTR model contains unidentified nuisance parameters. A solution consists in replacing the transition function $g(q_{it};\gamma,c)$ by its first-order Taylor expansion around $\gamma=0$ and by testing an equivalent hypothesis in an auxiliary regression. Then, we obtain:

$$y_{it}=\alpha_i+\beta_0 x_{it}+\omega_1 x_{it}^2+\varepsilon_{it} \tag{7}$$

In this first-order Taylor expansion, the parameter ω_1 is proportional to the slope parameter γ. Thus, testing the linearity against the PSTR model simply consists of testing H_0: $\omega_1=0$ in this linear panel model. For this objective, we can apply standard tests like the F-statistics. As we can notice, Eq. (7) corresponds to the quadratic polynomial model, which is the econometric specification used in most previous studies for representing 'the Kuznets curve'. Therefore, this point empirically justifies the idea of regime-switching in the analysis of CO_2 emissions intensity by showing that the quadratic model derives from a PSTR specification. If we have rejected the linearity hypothesis, we can check that there is no remaining nonlinearity. The issue is then to test whether there is one transition function or whether there are at least two transition functions defined as:

$$y_{it} = \alpha_i + \beta_0 x_{it} + \beta_1 x_{it} g_1(q_{it};\gamma_1, c_1) + \beta_2 x_{it} g_2(q_{it};\gamma_2, c_2) + \varepsilon_{it} \tag{8}$$

The logic of the test consists of replacing the second transition function by its first-order Taylor expansion around $\gamma_2 = 0$ and then testing linear constraints on the parameters. If we use the first-order Taylor approximation of $g_2(q_{it};\gamma_2, c_2)$, the model becomes:

$$y_{it} = \alpha_i + \beta_0 x_{it} + \beta_1 x_{it} g_1(q_{it};\gamma_1, c_1) + \omega_2 x_{it}^2 + \varepsilon_{it} \tag{9}$$

and the test of no remaining nonlinearity is simply defined by H_0: $\omega_2 = 0$. If we reject H_0, we must check if there exist a third transition function, etc.

4. Empirical Results

4.1 Panel Unit Root Test

Gonzalez et al.'s (2005) PSTR model requires that the variables in the model should be stationary in order to avoid spurious regressions and go further estimations of the panel smooth transition regression. The first-generation panel unit root tests are all constructed under the assumption that the individual time series in the panel are cross-sectional independence, when on the contrary a large amount of literature provides evidence of the co-movements between economic variables. To overcome this difficulty, a second generation of tests rejecting the cross-sectional independence hypothesis has been proposed. Firstly, we need to check whether our sample is characterized by cross-sectional dependence and Pesaran's cross-sectional dependence tests are applied. In Table 2A, we find the rejection of the null hypothesis of non-cross-sectional dependence in Pesaran's CD tests except for LP variable; therefore, we need to take this dependence into account in our panel unit root test for all the variables except for LP. In this study, we employ Moon and Perron (2004) and PP-Fisher Chi-square panel unit root tests to examine the stationarity for all variables, respectively. Note that the Moon and Perron (2004) test using de-factored data allow for multiple common factors. Therefore, their use has to be recommended when cross-section dependence is expected to be due to several common factors. Table 2B shows the stationary results for all variables at 1% significant level.

Table 2A. Pesaran's cross-sectional dependence tests

Variable	*LCO_2*	*LGDP*	*LEU*	*LGFCF*	*LP*
CD statistic	3.28*	8.50*	5.58*	3.34*	0.26

Note. The CD statistic is asymptotically normally distributed and * indicates significance at 1% level.

Table 2B. Panel unit root tests

Method	Moon and Perron unit root test (2^{nd} generation)				PP- Fisher Chi-square unit root test (1st generation)
Variable	*LCO_2*	*LGDP*	*LEU*	*LGFCF*	*LP*
t(a)	-5.33*	-8.03*	-9.02*	-5.11*	41.31* (with individual effects & trends)
t(b)	-3.45*	-4.40*	-4.20*	-2.90*	

Note. Moon and Perron unit root tests are obtained in a model with individual effects and * indicates significance at 1% level.

4.2 Estimation and Linearity Test

Next, we examine whether there is a nonlinear relationship among LCO_2, LGDP, LGFCF, LEU, and LP, and to determine the numbers to the transition functions. Table 3 shows that the linearity hypothesis is strongly rejected. This first result confirms the nonlinearity of the CO_2 emissions, but more originally shows the presence of strong threshold effects determined by real GDP per capita level. It will be therefore, necessary in a second step, to determine the number of transition functions required to capture all the nonlinearity of the CO_2 emissions. In our second test of no remaining nonlinearity, the null hypothesis is not rejected. Thus, our model needs only one transition function. Parameters β_0 and β_1 for four exogenous variables, location parameter, smooth parameter and residual sum of squares are also reported in Table 3. We then analyze the parameter estimates of the final PSTR models. The big smooth parameter (13.7439) shows that the estimated transition function is sharp. This point is particularly important, since it implies that the heterogeneity of the CO_2 emissions elasticity can be reduced to a limited number of regimes with different slope parameters.

Table 3. Linearity test and parameter estimation for the PSTR model

Specification			PSTR	
Transition variable			$LGDP_{it}$	
Fisher Test of linearity			32.550***	(0.000)
Fisher Test of no remaining nonlinearity			1.798	(0.135)
Variables	*LGDP*	*LGFCF*	*LEU*	*LP*
Parameter β_0	-0.3394***	0.2585***	0.8773***	0.0061*
Parameter β_1	0.5187***	-0.3888***	-0.1070**	0.0048
Location parameter	9.9276			
Smooth parameter	13.7439			
Residual sum of squares	0.0232			

Note. *, ** and *** stand for 10%, 5% and 1% significant level.

4.3 Environmental Kuznets Curve

Given the parameter estimates in a third step, it is possible to compute, for each country of the sample and for each year, the time varying CO_2 emissions elasticity with respect to all exogenous variables, denoted in Eq.(3) to Eq.(6). The Figs. 1 and 2 report Real GDP/capita and transition function both by country and across years by country. The threshold value or 'income turning point' of real GDP per capita is US$20,488 (9.9276 in logarithm). We can see that the value of transition function is less than 0.5 only in Italy after year 1998 due to less real income per capita (less than US$20,488).

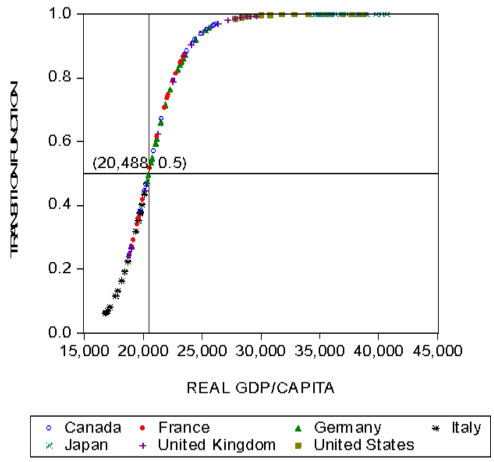

Figure 1. Real GDP/capita and transition function by country

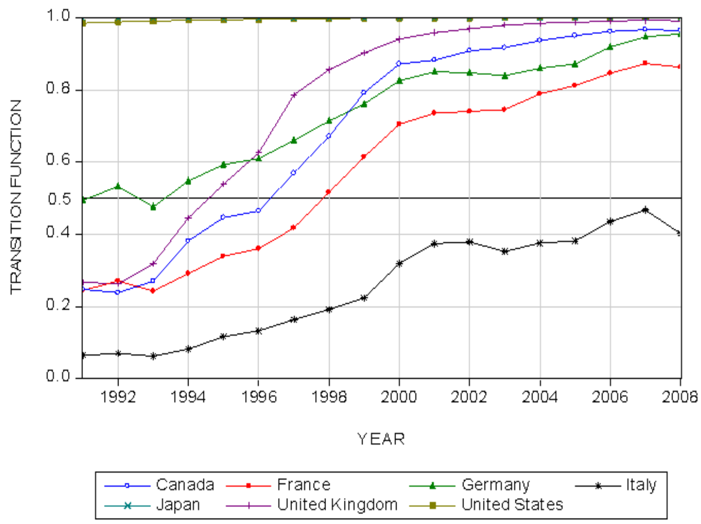

Figure 2. Real GDP/capita and transition function across years by country

Also, we observe the supported inverted-U shape in all countries between the CO_2 emissions and real GDP per capita in Fig. 3. This finding confirms the existence of EKC in G7 countries. In Fig. 4, the elasticity of CO_2 emissions per capita with respect to real GDP per capita is less than 1 in Japan after year 1991, in the UK after year 2005, and in the USA after year 1992, which supports that the environmental quality is a necessary good in these three countries but a luxury good in the rest of G7 countries.

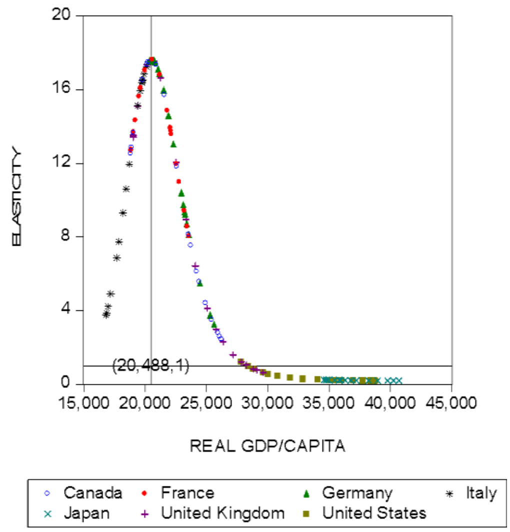

Figure 3. Estimated elasticity respecting LGDP by country

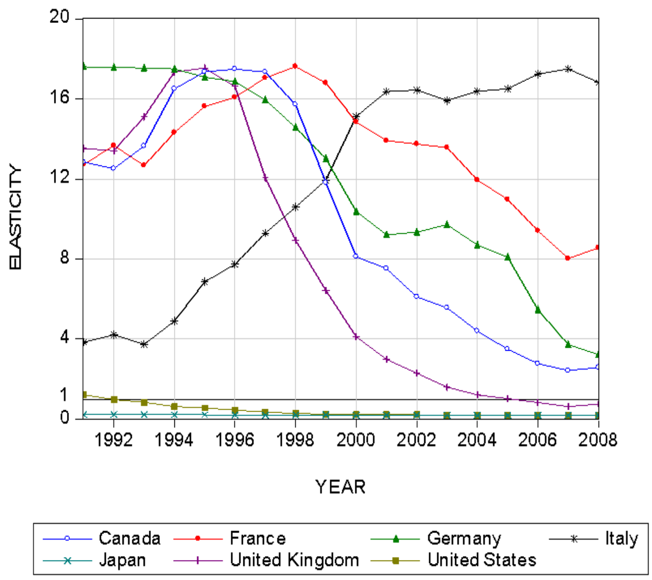

Figure 4. Estimated elasticity respecting LGDP across years by country

Figs. 5 and 6 show the estimated elasticity respecting LGFCF both by country and across years by country. In Fig. 6, we can see that there is negative elasticity of CO_2 emissions with respect to LGFCF after year 2000 except for Italy, which means that 6 out of G7 countries have experienced CO_2 emissions reduction due to the transition from industrial to service base economy. Figs. 7 and 8 report the estimated elasticity respecting LEU by country and the estimated elasticity respecting LP by country. In Fig. 7, we can see the CO_2 emissions gradual reduction per unit of energy use when the countries become richer.

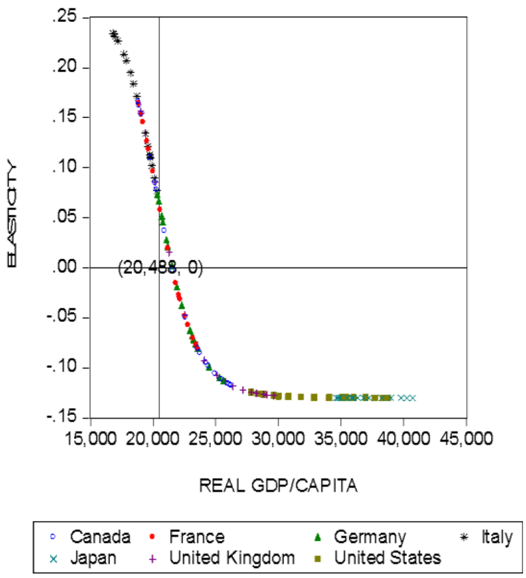

Figure 5. Estimated elasticity respecting LGFCF by country

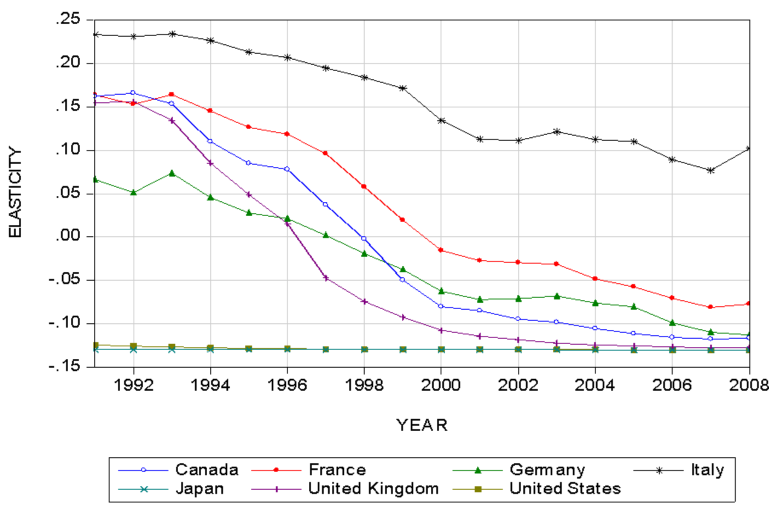

Figure 6. Estimated elasticity respecting LGFCF across years by country

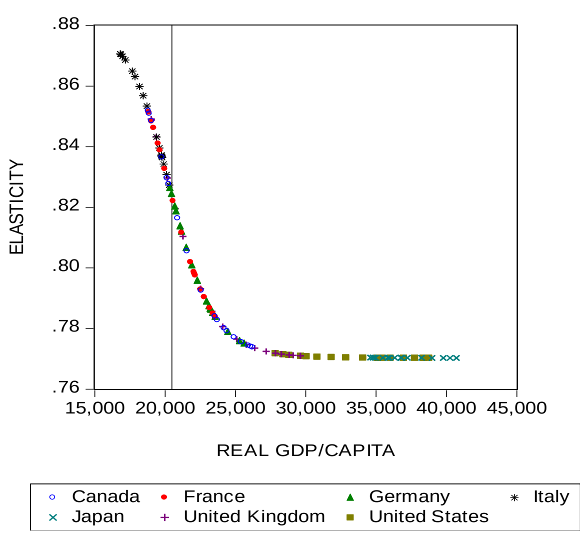

Figure 7. Estimated elasticity respecting LEU by country

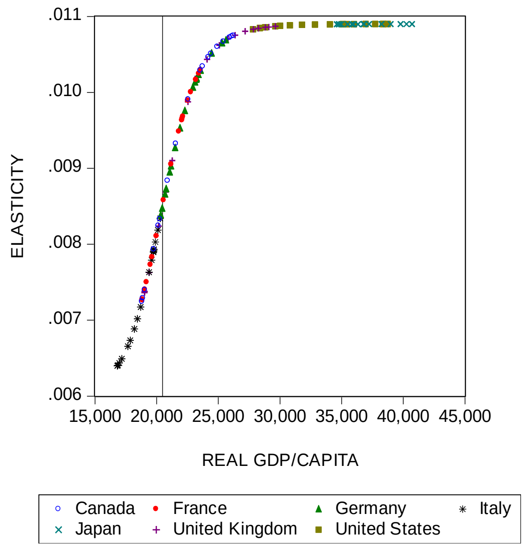

Figure 8. Estimated elasticity respecting LP by country

4.4 Policy Implications

The slopes of LGFCF, LEU, and LP can be different from the estimated parameters in Table 3 for the extreme regimes (β_0 for the first regime and $\beta_0 + \beta_1$ for the second). The negative signs of the parameters LGFCF and LEU indicate a decrease of the CO_2 emissions, that is, one more fixed capital investment or energy use will produce less CO_2 emissions in the second regime in Figs. 5 and 7. The transition from agricultural to industrial economies results in increasing environmental degradation as mass production and consumption grow in the economy in the first regime in Fig. 3. The transition from industrial to service based economy is assumed to result in decreasing degradation due to the lower impact of service industries in the second regime in Fig. 3. From these findings, we conclude that the transition variable of LGDP plays an important role in CO_2 emissions reduction when economies pass through technological life cycles, moving from smokestack technology to high technology.

5. Conclusions

This research applies a recently-developed nonlinear panel smooth transition regression (PSTR) model and takes into account the potential endogeneity biases to examine whether Environmental Kuznets Curve (EKC) exists in G7 countries over the period 1991-2008.

This research makes three contributions to the CO_2 emissions literature. First, we apply the panel smooth transition regression (PSTR) model of González et al. (2005) to investigate the relationship among CO_2 emissions per capita, energy use per capita, real gross fixed capital formation, real GDP per capita, and labor participation rate for G7 countries. Second, we complement the existing literature by simultaneously examining the impacts of energy use, real gross fixed capital formation, real GDP, and labor participation rate on CO_2 emissions and take into account endogenous determination of real GDP on the PSTR model for CO_2 emissions. Third, based on the characteristics of the PSTR model, we can consider the elasticity of CO_2 emissions changes with country and time to analyze the elasticity of heterogeneous countries and the potential impacts of structural breaks (parameter instability) on the CO_2 emissions elasticity in the panel framework. Based on the elasticity of the CO_2 emissions with respect to real income per capita, the environmental quality is a necessary good in Japan, the UK, and the USA, but a luxury good in the rest. Thus, there exists an inverted U-shaped relationship between CO_2 emissions and real income per capita with the threshold value of US$20,488, which is endogenously determined. This finding supports the existence of EKC in G7 countries. In other words, our results confirm that the richer is the greener in G7 countries.

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