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ENVIRONMENTAL KUZNETS CURVE AND AIR POLLUTION IN CITY OF LONDON: EVIDENCE FROM NEW PANEL SMOOTHING TRANSITION REGRESSIONS

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Abstract: The purpose of the paper is to test empirically the existence of the environmental Kuznets curve (EKC), using existing and new Panel Smoothing Transition Regressions (PSTR) in the city of London. More specifically, two new PSTR are proposed, the Gaussian and the Generalized Bell function used in Fuzzy Logic. Moreover, two air pollutants are examined using social data from the British Household Panel Survey. The air pollutants are the carbon monoxide (CO) and sulphur dioxide (SO_2). In particular the paper uses three regime smoothing transition regressions. More specifically, because the definition of the two regime smoothing regressions is not very clear, as three income classes exist, three regime smoothing regressions are proposed. Thus, the three regimes include the low, middle and high income. In the case of CO a negative relationship between air emissions and income is reported in low and high income classes, while midlle income households present a positive relation. On the contrary regarding SO_2, individuals and households with middle income pollute more, followed by high income class, while a negative association is pre-

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sented to low income. Therefore, EKC should be examined for a number of various air pollutants in micro-economic level too, because the patterns derived from the estimations are varied using different air pollutants.

AMS Subject Classification: C230, C450, Q530, Q560, Q580
Key Words: air quality, air pollution, environmental Kuznets curve, environmental sustainability, income, smoothing transition functions

1. Introduction

The relationship between economic growth and environmental quality has been an object of a long debate for many years. Through the fast exhaustion of the non-renewable resources, during the 21st century, and the irreversible dangers linked to climate changes, many scholars have expressed their worries that such a remarkable economic prosperity may not be sustainable in the future. Based on the report of Club of Rome if the future economic growth model remains unchanged and the population/industrial capital keeps growing exponentially, then the limited supply of both food and non-renewable resources will lead to the collapse of our production system and to the halt of our economic growth before 2100 [1].

Kuznets [2]predicted that the changing relationship between per capita income and income inequality is characterized by an inverted-U-shaped curve. This means that as per capita income increases, income inequality also increases at first and then starts declining after a turning point. Thus, in the early stages of the economic growth the distribution of income becomes more unequal, but then this distribution moves towards to greater equality as the economic growth continues [2]. As economy grows, environmental degradation and climate change are likely to have deleterious effects on natural and human systems, economies and infrastructure. The negative link between economic growth and environmental degradation is the reason to call for environmental policy responses and strategies at the local, regional, national and global level. Therefore, the Environmental Kuznets Curve (EKC) hypothesis argues for an inverted U-shaped relationship between economic development and environmental quality. More specifically, the environmental Kuznets curve is a hypothesized relationship between various indicators of environmental degradation and income per-capita.

The purpose of this study is twofold. Firstly, the EKC hypothesis is examined based on microeconomic level data, instead of macroeconomic, using the

Panel British Household Survey. Secondly, this study proposes two new transition functions, which are used in Fuzzy Logic. Furthermore, only the double threshold logistic transition function is explored in the literature. Thus, three additional double threshold transition functions are proposed and investigated in the current study.

The paper is organized as follows: Section 2 provides a briefly synopsis of previous researches in environmental Kuznets curve. Section 3 reviews the methodology of the models used in this study. Section 4 presents the data, and the research sample used in the estimations, while in Section 5 the empirical estimated results are reported and discussed.

2. Literature Review

Arrow et al.[3], Stern et al. [4] and Ekins [5] provide a number of reviews and critiques of the EKC studies. Grossman and Krueger, ([6], [7]) and Shafik and Bandyopadhyay, [8] suggest that at high income levels, material use increases in a way that the EKC is N-shaped. Shafik and Bandyopadhyay, [8] estimated the EKC hypothesis for 10 different indicators of environmental degradation, including lack of clean water and sanitation, deforestation, municipal waste, and sulphur oxides and carbon emissions. The authors found that the lack of clean water and sanitation declined uniformly with increasing incomes and over time; water pollution, municipal waste and carbon emissions increase; and deforestation is independent of income levels. In contrast, air pollutants conform to the EKC hypothesis with turning points at income levels between 300 and 4,000 US dollars. Panayotou, [9] using cross-section data and a translog specification, found similar results for these pollutants, with turning points at income levels ranging from 3,000 to 5,000 US dollars.

Panayotou, [9] also found that deforestation also conforms to the EKC hypothesis, with a turning point around 800 US dollars per capita; controlling for income, deforestation is significantly greater in tropical and in densely populated countries. Dinda [10] provides a very detailed and long survey of literature review about EKC hypothesis and environmental quality, but the researches are restricted on macroeconomic level. Cropper and Griffiths [11] estimated three regional EKCs for deforestation only. The regressions were for Africa, Latin America and Asia. They used pooled time series cross-section data on a regional basis. One of the main conclusions of this paper was that economic growth does not solve the problem of deforestation. Dijkgraaf and Vollebergh [12] estimated EKCs for CO_2 emissions relying on a panel data of OECD countries and time series regressions for each of the countries in the panel. They claim that although, analyzing the whole dataset, there is not a meaningful EKC for carbon emissions; for some individual countries this relationship may be significant.

3. Methodology

3.1. Model Specification

The basic smooth transition autoregressive (STAR) model, as discussed extensively in Granger and Terasvirta [13], Terasvirta [14] and van Dijk et al. [15], embraces two regimes, where the prevailing regime at time t is determined by the value of an observable variable. A STAR model of order p for a univariate time series y_{it}, which may represent for example the income in household i, for $i = 1$, 2....N and in time t, for $t = 1$, 2....T, is given by:

$$y_{it} = a_i + \sum_{j=1}^{p} a_{i,j} y_{it-j} + G(s_{it}; \gamma, c_i(\beta_{i,0} + \sum_{j=1}^{p} \beta_{i,j} s_{it-j}) + \epsilon_{it} \tag{1}$$

Alternatively, STAR model can be expressed as:

$$y_{it} = \acute{a}_i x_{it} + \acute{\beta}_i x_{it} G(s_{it}; \gamma, c_i) + \epsilon_{it}, \tag{2}$$

where x_{it}=(1,$\widetilde{x}_{it}$) with $\widetilde{x}_{it}$=(y_{t-1}, y_{t-2}.... y_{t-p}), $\acute{a}_i$=($a_{i,0}$, $a_{i,1}$.... $a_{i,p}$), β_i is similarly defined, a_i represents the fixed individual effect and ϵ_{it} denotes the error term or the residuals. The so-called transition function $G(s_{it};\gamma,c_i)$ is a continuous function that is bounded between 0 and 1. There are two possible interpretations of the STAR model. On the one hand, STAR model can be thought of as a regime switching model that allows for two regimes, associated with the extreme values of the transition function, $G(s_{it};\gamma,c_i)$=0 and $G(s_{it}; \gamma, c_i)$=1, where the transition from one regime to the other is smooth. On the other hand, the STAR model allows for a continuum of regimes, each associated with a different value of $G(s_{it};\gamma,c_i)$ between 0 and 1. The parameter c_i in relations (1) and (2) can be interpreted as the threshold between the two regimes, in the sense that the transition function changes monotonically from 0 to 1 as the transition variable s_{it} increases and $G(s_{it};\gamma,c_i)$=0.5 when s_{it}=c_i. The parameter γ determines the smoothness of the change in the value of the logistic function and, thus, the smoothness of the transition from one regime to the other. In addition, as $\gamma \to \infty$ the models in (1) or (2) become Panel

Transition Regressions (PTR). Luukkonen, et al. [16] proposed a linearity test by replacing the transition function with its Taylor approximation of a suitable order. At this point it should be noticed that this is not suitable when the transition function s_{it} is element of the vector x_t. Therefore, in the current study this test is not suitable, as the transition function is the income. Additionally, the choice of transition variable, in STAR models, is not straightforward, since the underlying economic theory often gives no clues as to which variable should be taken for the transition variable under the alternative. In the case examined this is not a shortcoming as based on EKC hypothesis the income is the transition function.

Based on STAR model methodology a Panel Smoothing Transition Regression (PSTR) is proposed. A feature that makes the PSTR model quite appealing is that individuals are not restricted to remain in the same group for all time periods if the so-called threshold variable that is used for grouping the observations is time-varying. Four transition functions are examined; the logistic, the exponential the Gaussian and the Generalized Bell function. These functions can be expressed by relation (3)- (6) respectively.

$$G(y_{it};\gamma,c_i) = (1+\exp(-\gamma(y_{it}-c_i)))^{-1}, \tag{3}$$

$$G(y_{it};\gamma,c_i) = (1-\exp(-\gamma(y_{it}-c_i)))^{2}, \tag{4}$$

$$G(y_{it};\gamma,c_i) = \exp\left(\frac{-(y_{it}-c_i)^2}{2\gamma^2}\right), \tag{5}$$

$$G(y_{it};\gamma,c_i) = \left(1+\left|\frac{y_{it}-c_i}{\gamma}\right|^{2b}\right)^{-1}, \tag{6}$$

with positive parameters c_i and γ. For relations (3) and (4) the following interpretation is possible. In the inner regime the individuals or households with low-middle income are included, while the individuals or households belonging in the high income class are expressed by the outer regime, which is characterized by the respective transition function. Therefore, PSTR can be seen as fuzzy regressions. Additionally, the three regime smoothing transition regression, which is the topic of interest in the current study, is defined as:

$$e_{it} = \acute{a}_i x_{it} + \acute{\beta}_{0i} G_1(y_{it};\gamma_1,c_1) + \acute{\beta}_{1i} G_2(y_{it};\gamma_2,c_2) + \epsilon_{it}, \tag{7}$$

where e_{it} denotes the air pollution levels and y_{it} determines both transitions and the second transition function is defined analogously to (3)-(6). Similarly, parameters c_1 and c_2 are the thresholds giving the location of the transition function and parameters γ_1 and γ_2 are the slopes of the transition functions.

3.2. Parameter Estimation

Estimating the parameters in the PSTR model (1) is an application of the fixed effects estimator and nonlinear least squares (NLS). First the individual effects a_i are eliminated by removing individual-specific means and then apply NLS. Fixed effects, as well as, clustered-robust standard errors take place on local authority districts. While eliminating fixed effects using the within transformation is standard in linear panel data models, the PSTR model calls for a more careful treatment. The model used in this study for air pollution can be rewritten as:

$$e_{it} = \acute{a}_i + \acute{\beta}_i x_{it}(\gamma, c_i) + \epsilon_{it}, \tag{8}$$

where e_{it} denotes the again air pollution emissions, y_{it} is the personal or household income, $\acute{\beta}_i$=($\acute{a}_i$, $\acute{\beta}_{ij}$) for j=1,2....p and x_{it}=$\acute{x}_{it}$, $\acute{x}_{it}(G(y_{it};\gamma,c_i)$. Matrix x_{it} contains the independent variables; the income and control variables. Subtracting the individual means from (8) yields:

$$\widetilde{e}_{it} = \acute{\beta}_i \widetilde{x}_{it}(\gamma, c_i) + \widetilde{\epsilon}_{it}, \tag{9}$$

where $\widetilde{e}_{it}$=e_{it}-$\bar{e}_i$, $\widetilde{x}_{it}$(γ,c$_i$)=(x_{it}-$\bar{x}_i$, $\acute{x}_{it} G_1(y_{it};\gamma,c)$-$\bar{w}_i(\gamma$,c), $\widetilde{\epsilon}_{it}$=$\epsilon_{it}$-$\bar{\epsilon}_i$ and $\bar{y}_i$, $\bar{x}_i$, $\bar{w}_i$ and $\bar{\epsilon}_i$ are individual means with $\bar{w}_i(\gamma$,c)=T$^{-1}\prod_{t=1}^{T}$G (y$_{it}$;γ,c). NLS are applied for the values determination of these parameters that minimize the concentrated sum of squared errors. These are defined as:

$$SSE(\gamma, c) = \sum_{i=1}^{N}\sum_{t=1}^{T}(\widetilde{e}_{it} - \hat{\beta}\widetilde{x}_{it}(\gamma, c))^2. \tag{10}$$

In this study the sign of derivative $\frac{\partial e_{it}}{\partial y_{it}}$ is examined. More specifically, of the derivative presents a negative sign then the EKC hypothesis might hold. This indicates that there is a negative association between personal or household income and air pollution.

Usually, before proceeding with the estimation of the STAR models, it must be determined whether the regime-switching effect is statistically significant. The null hypothesis of linearity is H_0:γ=0, which expresses no regime-switching effect in the data. However, under the null hypothesis the PSTR model is unidentified, and then classical tests have no standard distribution, which is the so-called Davies Problem ([17], [18]). Therefore, the PSTRs are estimated and then the parameters are examined whether are significant or not. Based on this criterion the proper transition function is chosen. A practical issue that deserves special attention in the estimation of the PSTR model is the selection of starting values for parameters γ and c. For the smooth transition model, it is often suggested that sensible starting values can be obtained by means of a grid search across the parameters in the transition function. This suggestion is based on the fact that (9) is linear in parameters β when γ and c are fixed. Hence, the concentrated sum of squared residuals (10) can be computed for an array or grid of values of γ and c.

An extensive two-dimensional grid search over γ and c is carried out. The model with the minimum sum of squared errors value from the grid search is used to provide initial estimates of parameters γ and c.. Then, the model is re-estimated by NLS. For parameters γ and c the initial values of 1 and the mean of transition variable (income) respectively are set up. The grid search for parameter c takes place in a short interval around the mean. For example for household income, where the mean is roughly 37,000, the grid search takes place in the interval [10, 11], which is expressed in logarithms, with increment 0.5. For parameter the grid search takes place in the interval [1 10] with increment 0.5. The estimations guarantee that the value of c should not be far outside the transition variable and the problem of near-singularity in the moment matrix is avoided. Teräsvirta [14] proposed that in some case it might be proper to divide the parameter γ with the sample standard deviation of the dependent variable, because the estimation of parameter γ may cause problems like overestimations. This is not a drawback in the case examined, based on the estimations, presented in next part of the study. Furthermore, one additional parameter is included in Generalized bell function, parameter b. This parameter indicates the width of the curve. The grid search takes place in the interval [0.1 2] with increment 0.1. Additionally, the logarithms of income are taken.

Another aim of the paper is the proposal of more efficient transition function. More specifically, there might be more efficient algorithms, instead of grid search, for the computation of parameters, but this paper shows that Gaussian and Generalized bell functions are more efficient regarding the statistical significance of the parameters, as well as, the number of iterations for the NLS procedure. In particular the maximum number of iterations is set up at 5,000. The maximum optimum number of NLS process, regarding proposed transition functions, is significant lower to the respective of logistic and exponential functions. Additionally, the Root Mean Squared Error (RMSE), which is a common statistical measure of regression performance, is lower concerning the proposed transition functions.

4. Data

The data used for the estimations come directly from the British Household Panel Survey (BHPS). The BHPS was started as a result of a proposal to the ESRC to establish an Interdisciplinary Research Centre (IRC) at the University of Essex. The proposal for the BHPS was very consciously seeking to emulate the success of household panel studies in other countries in Europe and North America. In particular the original inspiration was the Panel Study on Income Dynamics carried out by the Institute for Social Research at the University of Michigan since 1968. The wave 1 panel consists of some 5,500 households and 10,300 individuals drawn from 250 areas of Great Britain. Additional samples of 1,500 households in each of Scotland and Wales were added to the main sample in 1999, and in 2001 a sample of 2,000 households was added in Northern Ireland, making the panel suitable for UK-wide research [19]. It should be noticed that only the city of London, and not the greater area of London, is examined in this paper.

The variables used as control, are the education, gender, age, family size or household size, job status, marital status and house tenure. For regional and geographic effects the controlling is done based on individuals local authority district. There are various reasons why the specific demographic and household characteristics are obtained. For example it could be the case that a higher level of education, which generally increases with income, enhances environmental awareness and thereby amplifies the pressure made by inhabitants on policy makers to increase environmental quality or to decrease the rate of environmental degradation. Similarly the job or marital status can play an important role on EKC hypothesis. Additionally, the personal, as well as, the household income are examined. The paper examines the relation of air quality and personal/household income and investigates the assumption if the household income is relevant in explaining a persons relation with the air pollution and if it is possible to state that there are communitarian arrangements within the family.

The data for the air pollutants, can be found at the website of the Department for Environment Food and Rural Affairs DEFRA. Carbon monoxide (CO) is a colourless, odourless, tasteless, poisonous gas produced by incomplete burning of carbon-based fuels, including gas, oil, wood and coal. Carbon-based fuels are safe to use. It is only when the fuel does not burn properly that excess CO is produced, which is poisonous. When CO enters the body, it prevents the blood from bringing oxygen to cells, tissues, and organs [20].

Sulphur dioxide (SO_2) is a colourless gas, released from burning fossil fuels like coal and oil. It is one of the main chemicals that cause acid rain. Usually, power stations and oil refineries are the main sources of sulphur dioxide. Additionally, (SO_2) has long been recognised as a pollutant because of its role, along with particulate matter, in forming winter-time smogs [20].

Weather and meteorological data come directly from MetOffice (www.metoffice. gov.uk) and National Climatic Data Centre (http://www.ncdc.noaa.gov). More specifically, the weather data used is the average temperature, the precipitation and the wind speed. The data period used in the current study covers the waves 1-18 or years 1991-2009.

5. Empirical Results

In Table 2 the Logistic and Exponential PSTR results are reported. Also the standard errors are presented between the brackets. As it can be observed the coefficients are insignificant, except from the parameters in the first regime. In Table 3 the results with Gaussian and Generalized bell transition function are presented. The results indicate that based on Root MSE, the parameters significance and the number of iterations; the proposed transition functions outperform the conventional ones. The only exception is the Root MSE for Exponential function, which is 0.705. Based on results of Table 3, there is a positive association between air emissions and personal or household income for the middle class. On the contrary this relationship becomes negative for high income households, and the magnitude is higher followed by low income individuals and households. The estimations regarding personal income with Gaussian function are insignificant. Moreover, other researches found, as the EKC hypothesis claims, an inverted-U shaped curve. The results of Table 3 indicate that a cubic, instead of a quadratic relation, might exist. Additionally, concerning the estimations obtaining Generalized bell transition function and personal income, parameters b_1 and b_2 are 0.587 and 0.600, but only b_2 is significant at 5% level. Furthermore, parameters b_1 and b_2, in the case of household income, are 1.156 and 0.877 and statistically significant at 10% level.

Similarly, the results for Sulphur dioxide and the exponential transition function, show that all the income categories contribute negative to air emissions, regarding the personal income. On the contrary, based again on the results of Table 4, in the case of household income, only the results of exponential transition function are significant. The estimates show that there is a positive relationship between air pollutants and income. More specifically, the low income households contribute in a negative way to air pollution, while the middle income contributes positive and more, followed by richer households. The same conclusion is derived by Gaussian and Generalized bell transition functions. Based on Tables 4 and 5, the proposed transition functions outperform the conventional using the same criteria mentioned previously. Moreover, regarding personal income, parameters b_1 and b_2 are 0.511 and 0.628 respectively, but insignificant. On the other hand, in the case of household income parameters b_1 and b_2 are 0.563 and 0.828 respectively and statistically significant at 1% and 5% level.

Generally, EKC hypothesis does not hold in both air pollutants examined. More precicely, there might be a cubic relationship, rather a linear or quadratic. Moreover, only two majir air pollutants have been examined, while there are other major pollutants, as nitrogen dioxide or nitrogen oxides, as well as, secondary pollutants, like ground-level ozone and especially particulate matter. Finally, most researches examine macroeconomic level, like country level, and not individual or household level. Additionally, most studies use conventional panle data procedures as fixed and random effects, while also this paper proposes and examines two additional transition functions.

6. Conclusion

This paper suggests further empirical investigation of EKC hypothesis in additional microeconomic level data using switching regime regressions. Furthermore, STAR models have been inspired by fuzzy logic and artificial intelligence techniques, therefore alternative transition functions are proposed in this study, as the Gaussian and the Generalized Bell functions, but additional functions can be used as well, like the triangle and the trapezoidal among others. Moreover, simulated annealing algorithm can be used instead of grid search procedure. Furthermore, neural networks with error backpropagation algorithm or neuro-fuzzy systems can be used. Generally, fuzzy rules can be incorporated or other training or computational methods can be applied instead to nonlinear squares. Finally, free-derivative procedures, like genetic algortihms, can be used in order to compute the parameters γ and c.

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Appendix

Variable	Mean	Standard Deviation	Min	Max
Personal Income	9,193.611	14,498.68	0	1,190,309
Household Income	27,729.92	22,827.92	0	1,205,210
Carbon Monoxide	0.443	0.398	0	6.7
Sulphur Dioxide	7.457	8.343	0	291

Table 1: Summary statistics for income and air pollutants

Logistics PSTR		
Coefficient	personal income	household income
α_{00}	0.797 (0.416)*	1.779 (0.455)***
α_{01}	0.030 (0.013)**	-0.037 (0.057)
β_{00}	-0.333 (0.411)	-0.006 (0.005)
β_{01}	0.027 (0.030)	0.461 (0.290)
β_{10}	-0.0002 (0.005)	-1.970 (0.790)**
β_{11}	0.002 (0.003)	0.165 (0.233)
c_1	7.951 (7.577)	7,878 (7.655)
c_2	9.433 (8.127)	9.971 (2.346)***
γ_1	1.057 (0.764)	2.913 (10.626)
γ_2	3.317 (4.330)	1.306 (2.707)
Threshold 1	2,838	5,079
Threshold 2	12,494	21,397
N.observations	1,544	2,380
No.iterations	4,745	4,878
Adjusted R^2	0.0185	0.0189
Root MSE	0.700	0.768
Exponential PSTR		
α_{00}	1.628 (0.273)***	1.851 (0.322)***
α_{01}	-0.102 (0.027)***	-0.105 (0.026)***
β_{00}	-0.003 (0.002)	0.078 (0.117)
β_{01}	-0.006 (0.005)	-0.015 (0.025
β_{10}	0.025 (0.018)	0.253 (0.545)
β_{11}	-0.008 (0.006)	-0.006 (0.013)
c_1	7.951 (8.253)	8,050 (7.965)
c_2	9.756 (10.075)	10.256 (13.144)
γ_1	2.566 (1.871)	0.971 (0.475)**
γ_2	1.322 (1.457)	5.622 (14.418)
Threshold 1	2,838	3,134
Threshold 2	17,257	28,453
No.observations	1,544	2,380
No.iterations	4,397	4,178
Adjusted R^2	0.0185	0.0153
Root MSE	0.701	0.705

***, ** and * denote sig. at 1%, 5% and 10% level

Table 2: LPSTR and EPSTR Estimates for Carbon Monoxide (CO)

Gaussian PSTR		
Coefficient	personal income	household income
α_{00}	0.499 (0.106)***	1.337 (0.242)***
α_{01}	0.024 (0.024)	-0.061 (0.023)***
β_{00}	0.434 (0.503)	0.152 (0.614)
β_{01}	0.041 (0.061)	0.111 (0.008)**
β_{10}	0.566 (10.016)	-0.197 (0.232)
β_{11}	-0.084 (0.919)	-0.068 (0.005)***
c_1	8.200 (0.178)***	8.555 (0.319)***
c_2	10.942 (5.100)**	11.099 (0.015)***
γ_1	0.215 (0.143)	0.036 (0.009)***
γ_2	1.145 (1.877)	0.017 (0.003)***
Threshold 1	3,641	5,192
Threshold 2	56.500	66,050
No.observations	1,544	2,380
No.iterations	396	787
Adjusted R^2	0.0366	0.0492
Root MSE	0.696	0.756
Generalized bell PSTR		
α_{00}	1.386 (0.394)***	1.310 (0.351)***
α_{01}	-0.091 (0.037)**	-0.082 (0.034)**
β_{00}	2.777 (4.500)	-5.739 (3.140)**
β_{01}	0.730 (0.256)***	0.879 (0.365)**
β_{10}	0.376 (0.566)	-3.471 (4.175)
β_{11}	-0.976 (0.525)*	-0.385 (0.017)***
c_1	8.112 (0.293)***	8.577 (0.319)***
c_2	10.828 (0.256)***	11.063 (0.006)***
γ_1	0.523 (0.157)***	0.920 (0.427)**
γ_2	0.496 (0.150)***	0.530 (0.090)***
Threshold 1	3,334	5,308
Threshold 2	50,412	63,767
No.observations	1,544	2,380
No.iterations	248	95
Adjusted R^2	0.0441	0.0612
Root MSE	0.693	0.752

***, ** and * denote sig. at 1%, 5% and 10% level

Table 3: GPSTR and GbPSTR Estimates for Carbon Monoxide (CO)

	Logistics PSTR	
Coefficient	personal income	household income
α_{00}	4.668 (1.117)***	0.866 (4.494)
α_{01}	0.600 (0.279)**	0.858 (0.674)
β_{00}	-1.052 (0.076)***	-0.195 (0.753)
β_{01}	0.088 (0.015)***	0.014 (0.055)
β_{10}	-0.001 (0.027)	0.352 (0.466)
β_{11}	0.0001 (0.0019)	-0.293 (0.380)
c_1	7.375 (1.595)***	8.222 (9.127)
c_2	9.077 (8.155)	9.227 (10.175)
γ_1	1.185 (0.084)***	1.199 (0.958)
γ_2	3.527 (1.719)**	7.452 (241.646)
Threshold 1	1,596	3,722
Threshold 2	8,752	10,168
No.observations	1,775	2,621
No.iterations	$> 5,000$	$> 5,000$
Adjusted R^2	0.0171	0.0110
Root MSE	7.149	7.496
	Exponential PSTR	
α_{00}	14.249 (1.998)***	18.559 (11.180)*
α_{01}	-0.742 (0.201)***	-0.916 (0.277)***
β_{00}	0.002 (0.0006)**	1.480 (1.244)
β_{01}	-0.0057 (0.0022)**	3.307 (0.229)***
β_{10}	0.0001 (0.00005)**	0.123 (0.133)
β_{11}	-0.00013 (0.00005)**	2.301 (0.325)***
c_1	7,455 (2.125)***	8.687 (1.798)***
c_2	9.006 (1.133)***	9.547 (5.475)**
γ_1	1.527 (0.098)***	0.528 (0.707)
γ_2	2.433 (2.127)	4.174 (86.393)
Threshold 1	1,729	5,925
Threshold 2	8,063	16,234
No.observations	1,775	2,621
No.iterations	112	1,257
Adjusted R^2	0.0109	0.0081
Root MSE	7.165	7.491

***, ** and * denote sig. at 1%, 5% and 10% level

Table 4: LPSTR and EPSTR Estimates for Sulphur Dioxide (SO_2)

Gaussian PSTR		
Coefficient	personal income	household income
α_{00}	4.492 (1.108)***	9.537 (3.205)***
α_{01}	-0.109 (0.205)	-0.421 (0.222)*
β_{00}	51.191 (61.216)	-63.635 (35.727)*
β_{01}	4.893 (1.124)***	8.012 (4.466)*
β_{10}	-4.560 (3.585)	-37.438 (26.526)
β_{11}	0.235 (8.864)	3.986 (1.762)**
c_1	7.776 (0.131)***	7.937 (0.936)***
c_2	9.103 (0.486)***	9.772 (1.781)***
γ_1	0.739 (0.252)***	1.506 (0.368)***
γ_2	0.327 (0.159)**	1.455 (0.038)***
Threshold 1	2,382	2,799
Threshold 2	8,982	17,536
No.observations	1,775	2,621
No.iterations	48	63
Adjusted R^2	0.0278	0.0165
Root MSE	7.114	7.468
Generalized bell PSTR		
α_{00}	13.976 (3.454)***	12.046 (4.238)***
α_{01}	-0.922 (0.320)***	-0.774 (0.428)*
β_{00}	99.363 (88.038)	-78.544 (59.878)
β_{01}	11.230 (6.537)*	9.922 (2.397)***
β_{10}	-62.022 (60.868)	-34.028 (41.697)
β_{11}	7.211 (23.263)	3.594 (1.412)**
c_1	8.031 (0.670)***	8.093 (0.307)***
c_2	8.970 (1.007)***	9.963 (0.425)***
γ_1	.511 (0.048)***	0.437 (0.019)***
γ_2	0.604 (0.063)***	0.531 (0.091)***
Threshold 1	3,074	3,271
Threshold 2	7,863	21,226
No.observations	1,775	2,621
No.iterations	46	55
Adjusted R^2	0.0338	0.0160
Root MSE	7.094	7.470

***, ** and * denote sig. at 1%, 5% and 10% level

Table 5: GPSTR and GbPSTR Estimates for Sulphur Dioxide (SO_2)