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Carbon Dioxide (CO2) Emissions in Latin America: Looking for the Existence of Environmental Kuznets Curves

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Abstract

We estimated environmental Kuznets curve (EKC) for carbon dioxide for 16 Latin American countries using nonparametric, semi-parametric, and parametric specifications. Results indicated that most of the Latin American countries are still in the rising portion of the EKC with respect to CO_2 pollution.

Keywords: Parametric, Semiparametric, Nonparametric, Fixed and Random Effects Panel, CO_2, EKC, Latin American Countries

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I. Introduction

The relationship between economic growth and environmental quality has been extensively studied in recent years. Researchers have found interests in this relationship motivated by its usefulness for the definition of an appropriate balance between economic and environmental conditions for improving human welfare. If economic growth has a negative impact on environmental quality, efforts have to be made to diminish pollution damages. When this impact is positive, economic growth contributes to better environment conditions, and it is the desired result of rapid economic growth.

In the literature, this very active debate focuses on the existence of an environmental Kuznets curve (EKC) or inverted-U shape curve, which means that, starting from low levels of income per capita, environmental degradation increases but after a certain level of income or turning point it declines (Van Phu, 2001).

We study the relationship between carbon dioxide emissions and economic growth using panel data obtained from 16 Latin American countries from the period 1970-2000. We estimate parametric, semi-parametric, and non-parametric models to test for the existence or presence of EKC and determine to the turning points of this air pollutant. Latin American countries have been growing rapidly in the last 25 years, and their contribution on the CO_2 global emissions has increased as well. Urban areas have been expanding rapidly as a consequence of rural migration. This accelerated urban rise has increased deforestation rates in these countries affecting negatively to the environment. Furthermore industrialization has become a substantial sector of the

economy in these countries and agriculture has become a less important part of their economies.

The literature on this topic is divided in two groups: those have found no evidence for an inverted U-shape relationship between economic growth and environmental quality and those who proved the existence of the EKC. Our main objective is to analyze *ad hoc* parametric specifications against more flexible specifications such as nonparametric and semiparametric models to explore the existence of EKC.

II Understanding the Environmental Kuznets Curve

The EKC's origin lie in Kuznet's work in the 1950's on income inequality measures across developing countries, which documented a clear trend initially towards increased inequality as per capita income grows, with a subsequent fall. His work suggested an inverted U shape for a cross country plot for an inequality measure such as a Gini coefficient against income per capita (Jha and Murthy, 2003).

The environmental Kuznets curve is a hypothesized relationship between various indicators of environmental degradation and income per capita. In the early stages of economic growth degradation and pollution increase, but beyond some level of income per capita, which will vary for different indicators, the trend reverses, so that at high income levels economic growth leads to environmental improvement. This implies that the environmental impact indicator is an inverted U-shaped function of income per capita. Typically the logarithm of the indicator is modeled as a quadratic function of income per capita (Stern, 2003).

The EKC is essentially an empirical phenomenon, but most of the EKC literature is econometrically weak. Empirical studies are generally based on *ad hoc* parametric specifications with little attention paid to model robustness; yet different parametric specifications can lead to significantly different conclusions. Popular parametric functional forms are linear, squared, and a cubic polynomial functions of GDP per capita.

Stern (2003) suggests that the EKC concept emerged in the early 1990's with Grossman and Krueger's (1991) path breaking study of the potential impacts of NAFTA and Shafik and Bandyopadhyay's (1992) background study for the 1992 world development report. However, the idea that economic growth is necessary in order for environmental quality to be maintained or improved is an essential part of the sustainable development argument promulgated by the world commission on Environment and Development (1987).

Several authors believe that the EKC model is not as simple as it looks. Literature has demonstrated that there exist several factors affecting the inverse U shape relation between economic growth and environment, and they should be included in the analysis to prove with more confidence the proposed relationship. Variables, such as population, illiteracy rate, trade, political conditions, time and location conditions, have included in the different analysis to robustness the EKC model (Bhattarai and Hammig). We should also remember that the conditions to prove the existence of environmental Kuznets curve are not fixed for every pollutant or a specific geographic location.

III. Empirical Models and Estimation Procedures

A. Parametric Approach

Data involving time series and cross section analysis, usually referred to as panel data, are common in the literature. Many studies of the Environmental Kuznets Curve have used this type of data because it provides a wide source of information about the economic behavior and allows researchers to have greater flexibility in modeling differences and similarities between the data analyzed. In our study, we used panel data covering CO2 emissions, in thousands of metric tons, in 16 Latin America countries over a 30 year period.

In this paper, the EKC models have been analyzed either quadratic or in cubic specifications between CO 2 emissions and per capita income. We compare both specifications in our analysis to see which one adjust better to the Kuznets curve assumption. The common specifications of income in the panel data model used to describe the relationship between environmental degradation and per capita income are cubic and quadratic. The cubic functional form for income is given in equation (1).

$$CO2_{it} = a_i + ß1Y_{it} + ß2Y^2_{it} + ß3Y^3_{it} + ß4D_{it} + ß5PD_{it} + \mu_{it} \qquad (1)$$

Where, CO2 is carbon dioxide emissions, Y is per capita income, i and t represents indices of country and time, respectively. D represents the illiteracy rate, and PD is the population density for each country (individuals per kilometer). We hypothesize positive coefficient associated with illiteracy rate because we assume that higher illiteracy rate would be lead to higher contamination due to the lack of information concerning to the degradation of the environment. Population density is used as a proxy for human behavior, so if population densities are higher then it means higher contaminations levels

because deforestation rates increases due to the expansion of the agricultural frontier and also higher circulation of vehicles in the cities. Summarizing, we expect to have positive signs in the above parameters described. Seldon and Song (1994) explain that it is also important to remember that the relationship between population density and contamination can be expected to have negative sign for developed countries. The hypothesis underlying this assumption is that the more populated developed countries become then they are more concerned about the abatement of contamination.

The error component in the model can take different components. The specification of error components can depend solely on the cross section and time series. If the specification depends on the cross section, then we have $u_{it} = v_i + e_{it}$; and if the specification is assumed to be dependent on both cross section and time series, then the error components follow $u_{it} = v_i + e_t + e_{it}$. The term v_i is intended to capture the heterogeneity across individuals and the term e_t is to represent the heterogeneity over time. Furthermore, v_i and e_t can either be random or nonrandom, and e_{it} is the classical error term with zero mean and homoscedastic covariance matrix. The nature of the error structures leads to different estimation procedures depending on the specification. For this particular study, we estimated the models using one-way and two-way fixed and random effects models with F tests and Hausman tests used to evaluate the appropriateness of the model specification.

b. Semi-parametric Approach

Recent contributions on the semi-parametric modeling of the Environmental Kuznets Curve (Millimet and Stengos, 2003) suggest the specification of a semi-parametric partial linear regression model such as in Engel (1996) and Robinson (1998).

The model is flexible in capturing non-linearity between environmental degradation and economic growth, and it minimizes the tradeoff between variance and bias (Hardle, 1990). Consistent with previous parametric diagnostics, the panel data model is specified as a fixed effect error components model, which can be written as:

$$CO2_{it} = X_{it}ß + g(Y_{it}) + \mu_{it} \qquad (2)$$

Where X_{it} is a set of parametric variables of country characteristics such as population density and illiteracy rate, Y_{it} is per capita income, $g(Y_{it})$ is an unknown, assumed to be relatively smooth, function of income that can be approximated non-parametrically, typically through polynomial terms of powers two or at the most three. The function $g(Y_{it})$ is the non-parametric specification and the Y_{it} powers (1,2,3) are the smoothing variables. The degree of smoothness, often called the smoothness parameter, controls the trade off between smoothness and goodness of fit. Our analysis includes the TPSPLINE procedure as a method to fit our data. The TPSPLINE procedure uses the penalized least squares method to fit the data with a flexible model in which the number of effective parameters can be as large as the number of unique design points.

The use of the TPSPLINE procedure is very useful in our analysis because it provides penalized least squares estimates, supports the use of multidimensional data, fits both semi-parametric and non-parametric models, provides option to handle large data sets, and enables the researcher to choose a particular model by specifying the model degrees of freedom or smoothing parameter.

Non-Parametric Approach

We use a non-parametric specification to evaluate the relationship between CO_2 emissions and per capita income. This specification enables us to avoid specifying ad hoc

parametric functional form, e.g. per capita income as a linear, quadratic, or cubic function of environmental degradation or in our case CO2 emissions. Parametric functional forms are often restrictive and imprecise.

To avoid any ad hoc parametric functional form, our study applies the following non-parametric model:

$$CO_{2it} = g_t(Y_{it}) + \mu_{it} \qquad (3)$$

Y_{it} is per capita income, $g(Y_{it})$ is an unknown, assumed to be relatively smooth, function of income that can be approximated non-parametrically, typically through polynomial terms of powers two or at the most three. The function $g(Y_{it})$ is the non-parametric specification and the Y_{it} powers (1,2,3) are the smoothing variables. Our non-parametric analysis includes the procedures for non-parametric density estimation and non-parametric regression. The KDE procedure in SAS (Version 9) computes non-parametric estimates of univariate and bivariate probability density functions using the method of kernel density estimation. An important issue in the application of kernel density estimation is the choice of bandwidth, and the procedure provides several methods for automatic bandwidth selection. The LOESS procedure implements a non-parametric method for estimating local regression surfaces that allows great flexibility because it requires no assumptions about the parametric form of the regression surface. The LOESS procedure fits non-parametric models and supports the use multidimensional data, and multiple dependent variables.

IV Data

We used data on carbon dioxide in thousands of metric tons collected by the World Bank Development data for 16 Latin American countries for a 30 year period (1970-2000). CO_2 emissions data has been collected since last century, and it is one of the most important air contaminant in the world. CO_2 emissions are considered as one of the pollutant contributing the green house effect. There are different air contaminants such as SO_2, NO, methane, and others, but we feel that CO_2 is one or the most important air pollutant emission in Latin America. Rapid urbanization in Latin American cities has rapidly increased the emission of this gas. In addition, higher rates of deforestation have increased carbon dioxide emissions contributing to the green house effect. The green house effect contributes to climate and atmospheric changes affecting temperature and biophysical factors.

Per capita income is measured in dollars, and the data was found in the World Bank economic indicators for Latin America. Population density is measured by the number of people per square kilometer, and it was also obtained by the data above mentioned. Illiteracy rate is calculated as a percentage of the population from 15 years and above that cannot read.

V. Results

Descriptive statistics of the sample data are presented in table 1. The average emissions of carbon dioxide for Latin America are 9548.57 thousands of metric tons per year. The average per capita income is $ 2,588.99, but the gap among countries is very wide. Countries such as Honduras and Nicaragua ave per capita incomes ranged from

$408-600 dollars whereas Argentina has per capita income above $ 6,000 per year. Population density ranged from a minimum of 4 people per square kilometer to 303 people per square, and the illiteracy rate raged from 2.25% (Costa Rica) to 54.81% Nicaragua.

Parametric Results

The regression results for the fixed effects models are presented in table 2 and table 3. The expected signs of the estimated coefficients for one-way fixed effects quadratic specification were not as expected for illiteracy rate and population density, but income has the expected sign. Income, population density, and illiteracy rate present statistical significance. The estimated turning points were $47,318.3 (quadratic) and $10,668 (cubic). The F-statistics for testing the joint significance of the individual effects are given under the F-value column of table 2.

The two-way fixed effects model is presented in table 3. The turning point for the quadratic estimation is lower than the quadratic specification for the one-way fixed effect. The cubic estimation presents a smaller difference between the cubic estimation of the one-way fixed effect. The parameters for the quadratic specification present statistical significance excluding the square per capita income parameter. On the other hand, the cubic fix-two way effect is not statistical significant for the three income parameters

The regression results for the random effects model are presented in table 4 and table 5. The turning points are very similar compared to the turning points of the one-way fixed effect model. The R-square value was very low for this specific model. The parameters were statistical significant in the quadratic specification. It is also important to notice that the standard deviation of the turning point for the quadratic specification is

very high. The turning points for the cubic specification have lower standard deviation.

Two way random effects parameters were very significant for the population density and illiteracy rate parameters. Income square was not significant in the quadratic specification. In the cubic specification, the three income parameters were highly insignificant. Both illiteracy rate and population density presented negative sign for their respective parameter estimators. The turning points for the cubic specifications in both one and two way random effects were relatively similar. The two way specification models in both quadratic and cubic function had more realistic turning points because the one way models had turning points very high, so it means that income as high as $47,318 would be needed to decrease CO2 emissions. The average per capita income for Latin American countries was $2,589, so to reach income levels as obtained in the one way models is going to take long time to reach it. Finally, we can say that the parametric specifications, fixed and random effects, are not significant enough to prove the existence of the Environmental Kuznets Curve. Probably, the best specification was the quadratic fix two ways effect compared with the rest of parametric specifications, but it was not significant enough to confirm the presence of an inverted U-shape between economic growth and CO2 emissions in Latin American countries.

Semi-Parametric Results (PROC TPSPLINE)

Results of the TPSLINE method are presented in figures 1, 2 and 3. Figure 1 explains the predicted carbon dioxide emissions with respect to the real carbon dioxide emissions with a quadratic specification. We can notice that predicted and real values are not very similar because predicted values do not exceed 3,000 metric tons, and the real values go beyond 8,000 metric tons. The shape presented in this specification is not clear

enough to determine a relationship of an inverted U-shape between carbon dioxide and per capita income. The next figure expresses the same relationship in the income and CO2 pollution. We can see that the shape of the cubic specification is very similar to the quadratic, so conclusions are basically the same. In other words, the shape is not clear to determine a pattern between the predicted and the real values because they are different.

The last figure analyzed with the PROC TPSPLINE procedure describes the predicted carbon dioxide emissions in thousands of metric tons and real per capita income. With this graph, we can notice that lower income are related with lower predicted carbon dioxide emissions, and middle and upper level of income are related with higher carbon dioxide concentrations We can not make a specific conclusion of the data presented in that figure because there is not a clear pattern or relationship between these two variables.

Non-Parametric Results (PROC LOESS and PROC KDE)

We start this non-parametric discussion with the PROC LOESS specification. The figure 4 presents the confidence interval of the predicted values with respect of real carbon dioxide emissions and real per capita income. We can notice that the model captures the data in two sections: the beginning and the end. The middle barely captured by the LOESS specification because there are many upper and lower points that the model does not fit. This model used a smoothing parameter of 0.89 to fit this data, and it is the best fit found. Finally, we will conclude that the non-parametric model capture most of the data in the income range of $500-$3,000 and in the income range of $6,000-$8,000. It is also important to remember that most of the parametric specifications

presented turning points in the range of $7,000-$12,000, so the last range of the non-parametric LOESS procedure is part of the turning points in the parametric models.

Figure 5 presents the correlation between income and carbon dioxide as obtained from the PROC KDE procedure. The correlation value was 0.56 which means these two variables are not highly correlated. It can be demonstrated with the shape of graph 8 where the shape is expected to be in the middle with higher correlation. Our figure is located in the right corner, and it suggests a low correlation

VI. Conclusions

This paper analyzed three different approaches to estimate the relationship between carbon dioxide emissions and per capita income. We included in our data 16 Latin American countries using a 30 years period. The importance of this topic for this specific area is that Latin American countries have been urbanizing very fast in the last two decades, and this urbanization has created environmental concerns affecting the world welfare.

First of all, we can say that the parametric specifications, fixed and random effects, are not significant enough to prove the existence of the EKC. Probably, the best specification was the quadratic two-way fixed effects model compared with the rest of parametric specifications, but it was not significant enough to confirm the presence of an inverted U-shape between economic growth and CO_2 emissions in Latin American countries.

TPSLINE was used in the semi-parametric approach. The results do not show relationship between carbon dioxide and per capita income. Our quadratic and cubic

specifications were very similar in shape, and we noticed that predicted and real values were different as predicted values do not exceed 3,000 metric ton, where as the real values go beyond 8,000 metric tons.

Finally, the non-parametric specification included two different analyses: the PROC LOESS and the KDE procedure. In the first, we found that the model captures the data in two sections: the beginning and the end. The middle barely captured the LOESS specification because there were many upper and lower points that the model did not fit. The smoothing parameter used was 0.89.

The other specification used in the non-parametric approach was the KDE procedure and our main findings were that the variances for the two variables analyzed (carbon dioxide and income) were very high, and the correlation value was not high (0.56).

Table 1 Descriptive Statistics of the Data

Variables	Mean	Standard Deviation	Minimum	Maximum
CO2 (thousands of metric tons)	9548.57	15259.13	166.0000000	83930.00
Income per capita (thousand of $)	2.588990	1.7465474	0.4084995	8.4626260
Population Density	39.4314516	54.3950323	4.0000000	303.0000000
Illiteracy Rate (% of population above 15 years)	19.3856149	12.9024595	2.2560000	54.8149986
Number of Observations	**496**			

Table 2 One Way – Fixed Effects Model

Specifications	Income	Income Squares	Income Cubes	Population Density	Illiteracy Rate	T-points	F-value	R-square
Quadratic	3096.7 (1229.9)	-32.722 (140.2)	- -	-101.72 (23.3350)	-539.839 (54.3784)	47.3183 (185.2396)	239.34	0.9287
Cubic	1942.65 (2579.2)	266.752 (604.7)	-22.359 (43.913)	-102.082 (23.3641)	-540.872 (54.4585)	-2.71472 10.6683 (7.489745)	238.96	0.9288

Table 3 Two Way – Fixed Effects Model

Independent Variables	Income	Income Squares	Income Cubes	Population Density	Illiteracy Rate	T-points	F-value	R-square
Quadratic	2914.716 (1276.2)	-160.58 (145.3)	- -	-121.757 (23.9798)	-264.397 (109.2)	9.07559 (4.92)	78.84	0.9320
Cubic	2121.486 (2693.5)	44.0604 (628.8)	-15.21 (45.4694)	-121.984 (24.0133)	-267.765 (109.7)	-5.92102 7.85223 (23.37)	78.68	0.9320

Table 4 One Way – Random Effects Model

Specifications	Income	Income Squares	Income Cubes	Population Density	Illiteracy Rate	T-points	Hausman Test
Quadratic	3074.966 (1216.0)	-31.014 (139.2)	- -	-82.7283 (21.4546)	-496.801 (51.6487)	49.5738 (290.9323)	
Cubic	1848.635 (2545.4)	289.164 (600.1)	-23.9943 (43.7476)	-83.7987 (21.5381)	-499.612 (51.8037)	-2.44963 10.4839 (31.13648)	

Table 5 Two Way – Random Effects Model

Specifications	Income	Income Squares	Income Cubes	Population Density	Illiteracy Rate	T-points	Hausman Test
Quadratic	1216.6 (2.53)	-31.042 (139.3)	- -	-80.6313 (21.2774)	-491.854 (51.4394)	19.596 (240.8001)	22.79
Cubic	1840.786 (2546.1)	291.6181 (600.8)	-24.192 (43.8177)	-81.6174 (21.3540)	-494.5 (51.5872)	-2.42462 10.4608 (6.5584805)	22.74

Note: The numbers in parenthesis are standard errors.

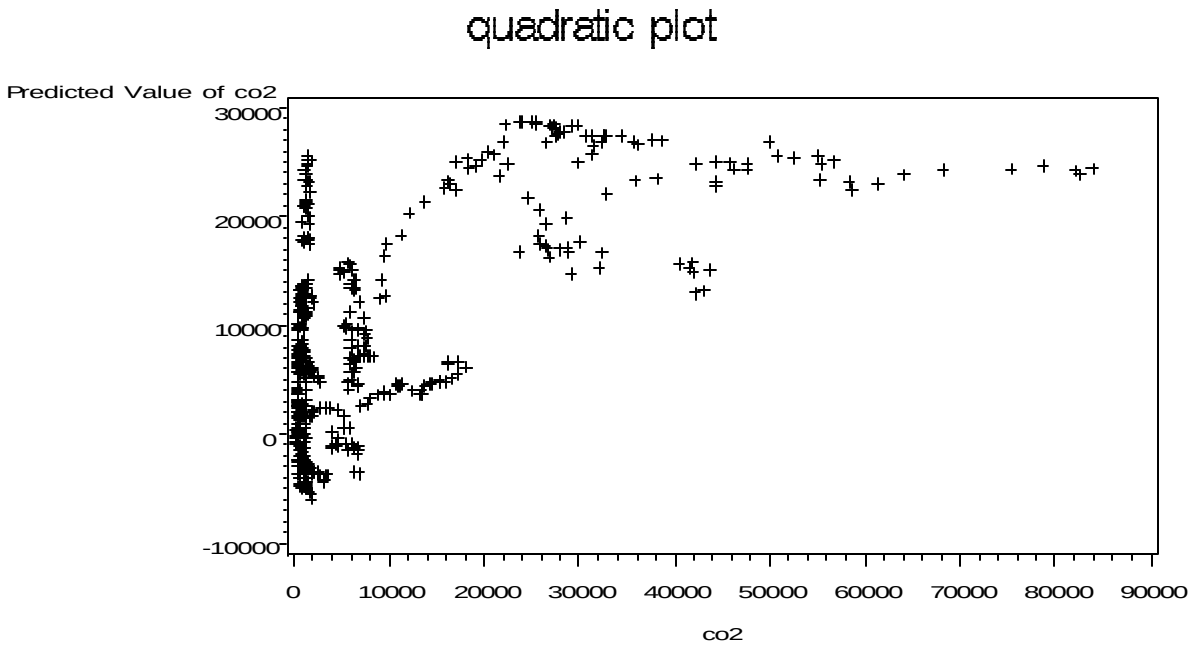

Fig. 1 Predicted CO2 Emissions and Real CO2 Emissions (Quadratic Form)

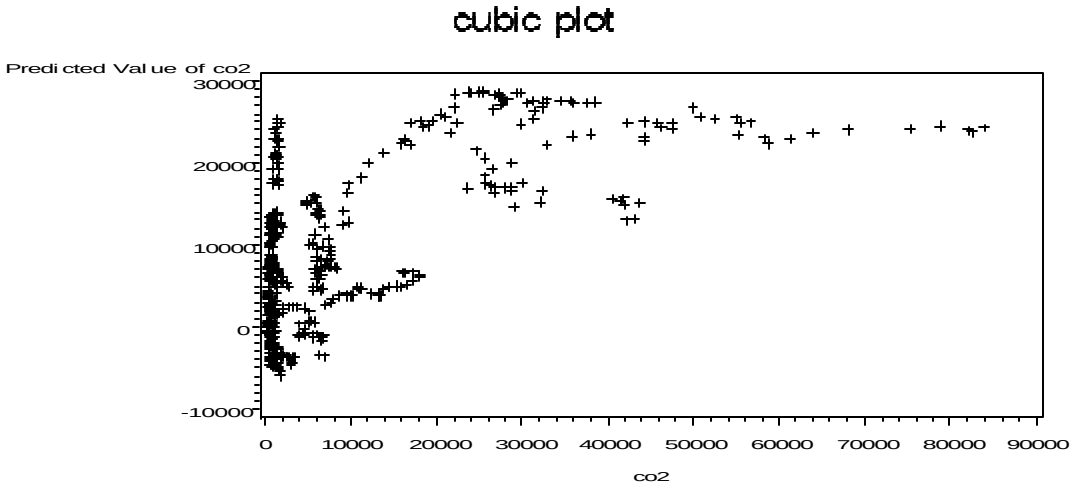

Fig. 2 Predicted CO2 Emissions and Real CO2 Emissions (Cubic Form)

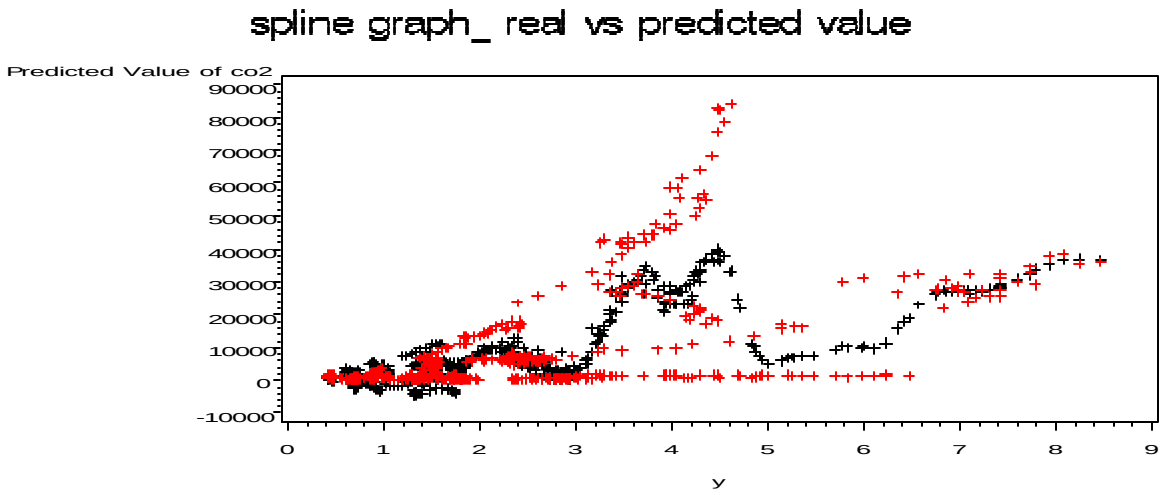

Fig. 3 Predicted CO2 Emissions and Real Per Capita Income

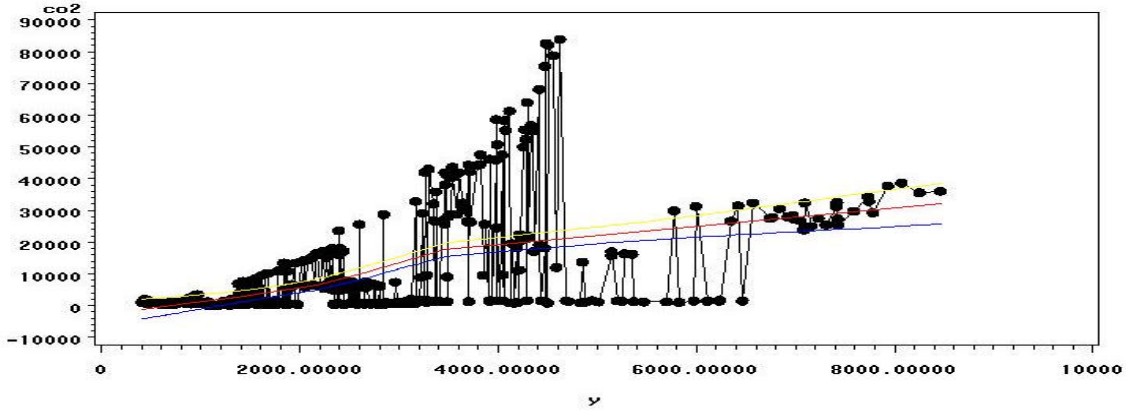

Fig. 4 Confident Interval for Predicted Values in the LOESS Procedure

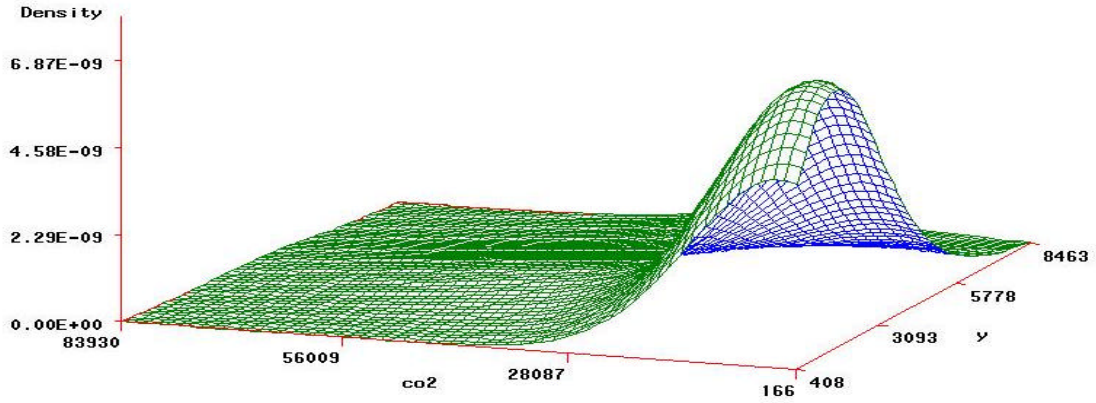

Fig. 5 Proc KDE Three-dimensional Graph

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