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Abstract
Over the years environmental issues have been playing a remarkable role in the global debate about the Earth future. Emissions of the "greenhouse effect" gases (GHG) are increasing, in despite of joint efforts to implement international agreements. In this context, this paper is aimed at investigating the Global Environmental Kuznets Curve (EKC) hypothesis for a sample of 167 countries over the period 2000-2004, using a fixed effect model with spatial dependence. Another objective is to evaluate the role of the Kyoto Protocol as a global policy in order to reduce CO_2 emissions per capita. To do so, a dummy variable, representing the countries that have ratified the Protocol is introduced into the right hand of regression. Besides, other three variables are inserted into the right hand of regression: the trade intensity, energy consumption per capita and population density. The econometric results, in principle, suggest the existence of an "N" shaped EKC, finding the following "turning points": US$ 12,342.34 and US$ 27,106.23. Another important issue is the negative coefficient, and statistically significant, for the dummy variable for the Kyoto Protocol, showing the potential importance of international agreements for reducing the overall amount of CO_2 emission per capita. Therefore, economic growth itself cannot replace multilateral policies that seek to reduce CO_2 emissions.

Key words: Environmental Kuznets Curve, CO_2 emissions per capita, spatial econometrics, Kyoto Protocol.

Introduction

Environmental risks and uncertainties from elevated consumption in the future are disturbing. Among the risks involved, the probability of climate change due to the greenhouse effect caused by gases emitted in the atmosphere can be identified. The most important of these gases is carbon dioxide (CO_2), which is generated by the burning of fossil fuels and pollution stemming from manufacturing plants. The accumulation of CO_2 and other gases in the atmosphere retains the solar radiation surrounding the Earth´s surface, provoking the global warming phenomenon. In the next decades this may imply sea level increases up to a certain point that will be able to inundate various coastal cities. Furthermore, this phenomenon may cause enormous problems to international agriculture and the trade system (WCED, 1987). In the late eighties a critical view started emerging from the developed and developing countries worried about how economic growth was taking place worldwide and its impact on the planet´s future. Hence there was a preoccupation about the excessive use of

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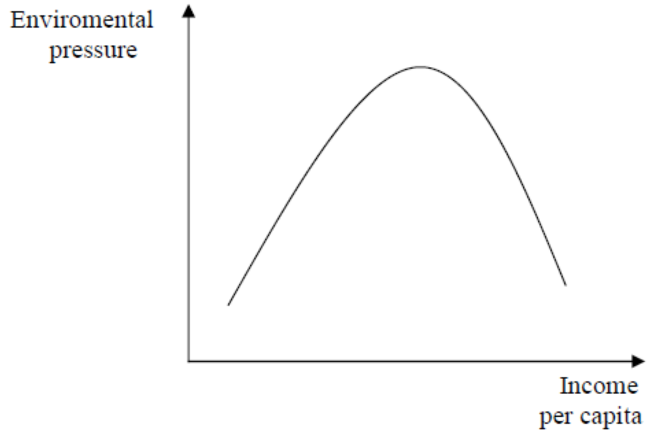
natural resources without considering the support capacity of the ecosystems around the world.

In this context, some authors have investigated a relationship called EKC (Environmental Kuznets Curve) in which environmental degradation measures increase as economic growth is generated up to a maximum. Afterwards, when a certain level of income per capita is reached, these measures decrease. According to Stern (2004, p. 1419), “the EKC proposes that indicators of environmental degradation first rise, and then fall with increasing income per capita”. The concept of EKC flourished in the early nineties to describe the time trajectory that a country’s pollution would follow as a result of its economic growth. When growth occurs in an extremely poor country, pollution emissions grow because the increase in production generates pollutants and because the country places a low priority on the control of environmental degradation. Once a country obtains a high enough degree of affluence, its priority switches to protection of environmental quality. If this income effect is strong enough, it will cause the decline of pollution. According to Deacon and Norman (2004), this line of reasoning suggests that environmental improvement does not come without economic growth.

So countries would go through development stages, guided by market forces and governmental regulation changes. In the first stage, marked by the transition from an agricultural economy to an industrialized one, economic growth implies pressure on the environment, as a consequence of creation and expansion of manufacturing plants. The next stage would be characterized by the maturation of society and industrial infrastructure. At this moment, the accomplishment of basic needs allows the growth of sectors which are less intensive in terms of resources and pollution. At the same time, technological improvement begins to reduce energy intensity. At last, in the third development stage, a de-linking would happen between economic growth and pressure on the environment, when the former does not imply the increase of the latter (Grossman and Krueger, 1995; Selden and Song, 1994; Shafik and Bandyopadhyay, 1992). Above a certain per capita income level (called the turning point), environmental quality would improve in accordance with economic growth. This means that the environmental impact is an inverted U shaped function in terms of income per capita, as shown in figure 1.

Figure 1. Environmental Kuznets Curve

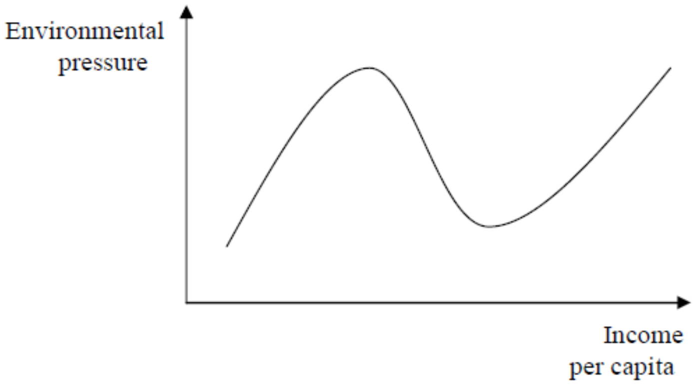


Source: Authors' elaboration.

The relationship between economic growth and environmental quality described by Grossman and Krueger (1991) can be decomposed into three effects, namely, scale effect, composition effect and technical effect. One expects that environmental pressure increases as output growth increases (scale effect). Nevertheless, this greater pressure can be nullified by the other two effects. For instance, it is possible that economic growth occurs mainly in sectors that pollute less (composition effect). It is also possible to admit that technological progress is able to countervail the greater production level (technical effect).

However, De Bruyn et al. (1998) believe that the EKC does not hold in the long run. So the inverted U shape would be only an initial stage of the relationship between economic growth and environmental pressure. Above a certain income level, there would be a new turning point after which the trajectory would become ascendant again, leading to an N shaped curve. This means that environmental degradation would come back at high economic growth levels.

Figure 2. Another Version of the Environmental Kuznets Curve



Source: Authors' elaboration.

In terms of global impact pollutants, since the nineteen century, some researchers have tried to demonstrate the association between carbon dioxide (CO_2) in the atmosphere and temperature elevation. However the initial response of the countries in relation to global warming was the Framework Convention on Climate Change (FCCC) originated at the Rio Summit in 1992. That the voluntary approach under FCCC would not generate any effective result in terms of policy measures was suddenly evident for many people around the world. Besides, the CO_2 emissions from some countries have increased since that time. This motivated public policy defenders to continue with meetings leading to the Kyoto Protocol in 1997 (Nordhaus, 1999). The Kyoto Protocol contains a specific compromise assumed by industrialized and transition economies to reduce their CO_2 emissions below their 1990 level along the period 2008-2012. However no compromise has been assumed by developing countries, grounded on the argument that the process of industrialization and development should not be limited by any constraint on generating energy and consumption (Galeotti and Lanza, 1999).

From a theoretical viewpoint, the EKC hypothesis is less likely for CO_2 emissions because this kind of pollutant causes problems on a global scale and, consequently, the social costs accruing from global warming accumulate along time and across countries. Generally, the evidence in favor of the EKC is found for environmental problems at the local level, like SO_2, NO_x[1]. When investigating pollutants whose control costs are large in terms of changes in consumption habits and whose effects are externalized in the atmosphere, like CO_2, for example, this relationship does not have robust empirical evidence in favor of an inverted U shaped EKC.

A linear relationship between CO_2 emissions and GDP per capita has been corroborated in some studies (Shafik and Bandyopadhyay, 1992). Other studies have found an N shaped function (De Bruyn et al., 1998; Holtz-Eakin Selden, 1995; Moomaw, and Unruh, 1997). Neither linear nor cubic relationship allows us to have an optimistic interpretation about the beneficial effects of economic growth on environmental preservation. By contrast, at higher levels of income, CO_2 emissions show an increase as income growth takes place (Friedl and Getzner, 2003)

Perhaps more important than the findings of the studies that test empirically the EKC hypothesis are the consequences of this relationship referring to environmental policy. However, Grossman and Krueger (1995) point out that, even for pollution indicators that demonstrate a fall after a certain level of income, the occurrence of this process is actually not guaranteed. Therefore economic growth itself does not guarantee the cure for problems related to the environment. Proper environmental policies play a fundamental role in the inversion of the trajectory of pollutants that follow the EKC hypothesis. Although the international community is favorable to sustainable development, public policies do not incorporate this compromise with environmental defense. The definition of concrete targets for reducing pollutant emissions at international conferences, as well as the public policies implemented by the majority of countries, are below the recommendation suggested by scientists and environmentalists as being indispensable to solving global warming. Of course, there are factors which intervene on political and economic systems to hinder the search for the social optimum at the moment of negotiating international agreements (Fray, 2001).

Although the EKC has been corroborated in several studies of air, water and soil pollutants, in the case of greenhouse effect gases, like CO_2 emissions, the empirical evidence is yet dubious. The majority of papers on EKC show panel data containing countries as the cross-section unit. The literature started studying this topic after Grossman and Krueger's paper (Grossman and Krueger, 1991) and since then several authors have published on the EKC. Table I lists the papers that estimated EKCs using CO_2 emissions as the dependent variable.

According to Stern (2004), the EKC hypothesis is an intrinsically empirical phenomenon, but most studies in the literature are weak in econometric terms. Generally, little attention has been dedicated to statistical proprieties of data used, such as spatial dependence or stochastic trends in time series. Besides, little consideration has been dedicated to model appropriateness issues, such as the possibility of omitted relevant variable bias. Most studies assume that, if the regression coefficients are individually or jointly significant and their expected signs are obtained, the EKC hypothesis is valid (Maddison, 2006; Rupasingha et al., 2004). In this context, Ruphasingha et al. (2004) remember that, although geographical areas (or cross-section units) form the basic unit for most EKC analysis, almost all studies in the literature have ignored spatial effects when analyzing this environmental phenomenon.

After Grossman and Krueger's paper there was a copious amount of EKC studies, using several degradation indexes, type of data and geographical regions (Fonseca and Ribeiro, 2005; Gomes and Braga, 2008; Halkos, 2003; Kaufmann et al., 1998; Panayotou, 1993; Perman and Stern, 2003; Santos et al., 2008; Selden and Song, 1994; Shafik and

[1] One calls NO_x when NO (nitrogen monoxide) and NO_2 (nitrogen dioxide) are denominated jointly.

Bandyopadhyay, 1992; Stern, 2000). More recent papers have included the control for spatial effects in the analysis of EKC, for example Maddison (2006) a cross-country study, Poon et al. (2006) for Chinese regions, Ruphasinga et al. (2004) for US regions and Stern (2000) for sixteen West European countries. Table I presents only the papers in the literature that used CO_2 emissions as the dependent variable. It is noteworthy that no paper has controlled for spatial dependence, even using geographical units. The paper for the most recent year is 2003 and for the largest sample size was with 34 countries.

Table I. Papers on EKC using Carbon Dioxide (CO_2)

Authors	Region	Period	Dependent variable	Type of data	Additional Variables	Turning point	Conclusion
Moomaw and Unhruh (1997)	16 countries	1950-1992	CO_2 emissions	Panel data	____________	$12,813	No EKC relationships are obtained.
Cole et al. (1997)	7 regions along the world	1960-1991	CO_2 emissions	Panel data	an intercept dummy, time trend and trade intensity variable	$25,100	The findings demonstrate that the global impact of CO_2 emissions has provided little incentive for countries to implement unilateral actions for these emissions.
Agras and Chapman (1999)	34 countries	1971-1989	CO_2 emissions and energy	Panel data	Trade variables and temporally lagged dependent variable	$62,000 for energy regression and $13,630 for CO_2 regression	Inverted U shaped curve between income and energy and between income and CO_2 emissions.
Dijkgraaf and Vollebergh (2001)	OCDE countries	1960-1997	CO_2 emissions	Panel data	___________	$15,704 and $13,959	The fact of many countries not reflecting the EKC pattern becomes makes the existence of a global inverted U shaped curve particularly improbable.
Arraes et al. (2006)	countries (sample size is not defined)	1980, 1985, 1990, 1995, 2000	CO_2 emissions and other indicators of development	Panel data	Dummy for Sub-Sahara African countries	_______________	An inverted U shaped curve was found.
De Bruyn et al. (1998)	4 countries (Netherlands, United Kingdom, USA, Germany)	1960-1993	CO_2 , NO_x and SO_2 emissions	Panel data	Related input prices	_______________	An inverted U shaped curve was not found.
Lucena (2005)	Brazil	1970-2003	CO_2 emissions	Time series	Trade openness variable	______________	Evidences for an EKC in the case of CO_2 emissions.

Source: Authors' elaboration.

Therefore the papers described above have obtained quite different results and conclusions on the existence of the EKC hypothesis. The reasons may be samples with different countries, diversified environmental degradation indicators and/or different econometric techniques.

This paper is aimed at contributing to the EKC literature by providing a more sophisticated econometric model, taking into account statistical proprieties and several controls both for spatial effects and other pollution determinants in order to improve the model fitness. The spatial relationships are very important in EKCs because countries' emissions per capita are affected by events occurred in neighboring countries. The several sources of these spatial relationships are discussed in Maddison (2006). One expects to contribute to the discussion about the "economic growth, international public policy and environment issue" and check if an inverted U shaped relationship can be observed globally, using panel data for 167 countries over the period 2000-2004, and controlling explicitly for spatial effects, namely, spatial dependence and spatial heterogeneity.

The present paper advances the discussion about EKCs mainly in four aspects. Firstly, an additional variable is inserted into the analysis to investigate whether or not countries that are signatory to the Kyoto Protocol are contributing effectively to emissions reduction. Secondly, it is noteworthy that no previous cross-national EKC study had this sample size (167 countries). Thirdly, the analysis is implemented over a recent period (2000-2004). Finally, as far as we know, this study is the first one to implement an EKC analysis for CO_2 emissions, controlling for spatial dependence.

The econometric results, in principle, rather suggest the existence of an "N" shaped EKC. Another important issue is the negative coefficient, and statistically significant, for the dummy variable of the countries that have ratified the Kyoto Protocol, showing the importance of multilateral agreements on reducing the overall amount of CO_2 emissions per capita.

Following this introduction, the paper is organized in four more parts. The second part describes the econometric methods adopted for the estimation of the EKC. The third part presents the sources of the data and the procedure of data preparation. The econometric results are reported, interpreted and discussed in the fourth part. The last part concludes.

Specification Issues

The model specification is based upon previous studies about the EKC that used some pollutant emission indicators as dependent variables. In this paper, nevertheless, only one pollutant emission measure is adopted, that is, carbon dioxide. This is because it is the main gas responsible for generating the greenhouse effect and, thereby, the phenomenon of global warming. On the other hand, variables like GDP per capita and its square are often found in the EKC literature and are inserted into the regression.

The functional form of the model is the following:

$$E_t = \mu + \rho W_1 E_t + Y_t \beta + \delta KP_t + X_t \psi + W_1 X_t \tau + u_t \quad (1.a)$$

$$u_t = \lambda W_2 u_t + \varepsilon_t \quad (1.b)$$

where $E_t = (E_{1t},..., E_{Nt})'$ is a vector of CO_2 emissions per capita; $\mu = (\mu_1,..., \mu_N)'$ stands for a vector representing non-observable effects; W_1 and W_2 are spatial weight matrices, which try to represent the spatial structure of dependence; W_1E_t is the spatially lagged dependent variable; Y_t is a matrix composed by three other vectors of variables denoting income per capita, squared income per capita and cubic income per capita, namely, $Y_t = [y_t, y_t^2, y_t^3]$, where $y_t = (y'_{1t},..., y'_{Nt})'$ and so on; KP_t is a dummy variable for countries that ratified the Kyoto Protocol each year, taking on the value one for countries that ratified Kyoto Protocol and zero otherwise.; $X_t = (X'_{1t},..., X'_{Nt})$ is a matrix representing other variables, which also influence the relationship between E and y. W_1X_t represents the spatial lag of variables X, which captures spatial spillover effects of CO_2 emissions per capita. W_2u_t is the spatial lag of errors u_t; and ε_t indicates an *i.i.d.* error term. The Greek symbols (β, δ, ψ and τ) stand for vectors of parameters to be estimated. Finally, ρ and λ are coefficients to be estimated. Johnston and Dinardo (1997) consider the panel data model useful because it is able to handle the problem of omitted relevant variables. Not taking into account the non-observable effects (μ) increases the risk of biasing the regression's estimates. Hence it is important to consider this kind of non-observable spatial heterogeneity in order to get consistent estimates.

This also means the panel data model can accommodate the spatial heterogeneity that is represented by region-specific, non-observable and time invariant intercepts. So the panel data control for non-observable effects by means of two different models: a fixed effect model and a random effect model. The difference between these two models lies in the assumption about the correlation of explanatory variables with the non-observable effects. If, at least, an explanatory variable is correlated with the non-observable effects, the fixed effect model is more appropriate. Nevertheless if the explanatory variables are not correlated with the non-observable effects, the random effect model is more proper. In this case, the non-observable effects are components of the error term.

If we pose restrictions on equation (1), we will have some spatial econometric models that take into account the spatial autocorrelation. If $\lambda=0$, $\tau=0$ and $\rho\neq0$, the spatial lag model emerges. This kind of model can represent spillover effects in the environmental degradation. If $\rho=0$, $\tau=0$ and $\lambda\neq0$, the spatial error model is obtained. This type of model is more appropriate when there are non-modeled factors that manifest in the residuals. The unrestricted model is a model with spatial lag and spatial error.[2] If $\rho=0$, $\lambda=0$ and the vector of coefficients $\tau\neq0$, the spatial cross-regressive model is obtained. If $\rho\neq0$, $\tau\neq0$ and $\lambda=0$, the spatial Durbin model accrues. If $\rho=0$, $\lambda\neq0$ and the vector of coefficients $\tau\neq0$, the spatial Durbin error model emerges.

The procedure adopted here is based on the following steps:

i) Estimate a pooled data model with no control for non-observable effects;

ii) Implement the Hausman test to define which non-observable effect model is appropriate, that is, fixed effect model or random effect model;

iii) Estimate the non-observable effect model determined by the Hausman test;

iv) Check the last regression's residuals for spatial dependence;

v) If there is no spatial dependence, stop the procedure and keep the non-observable effect model; otherwise, go to the next step;

[2] For more information on spatial models, see Anselin (1988) and LeSage and Pace (2009).

vi) Estimate several spatial models.
vii) Choose the best spatial model based on these two conditions: a) absence of spatial dependence in the model's residuals; b) given the last condition, choose the model with the smallest value of some information criterion.

Data

The sample contains 167 countries over the period 2000-2004. The reason for the choice of just five years is because of the difficulty of finding data for all countries over a longer period. As the data are international, the database is not immune to problems because some countries do not have advanced statistical agencies. However, the main source of the database is the United Nations Statistics Division (UNSD), whose main function is to gather, standardize and treat data from various countries. [3]

The dependent variable E_t is CO_2 emissions per capita (in metric tons). The choice of this variable as environmental degradation indicator is justified because this pollutant is the main component for the emergence of the greenhouse effect and global warming. The data comes from the United Nations Statistics Division (UNSD), which compiles information from two other sources, namely, CDIAC (Carbon Dioxide Information Analysis Center) and MDG (Millennium Development Goals). The reason to choose "emissions" and not "concentration" is because the emissions are linked to current economic activity levels, and thereby these emissions measure the potential for economic activity to degrade the environment and/or human health (Kaufmann et. al., 1998).

The variables contained in $Y_t = [y_t, y_t^2, y_t^3]$ indicate the shape of the EKC function. The main explanatory variable, GDP per capita, is measured in constant 2000 dollars and was obtained from the United Nations' estimates. The population data are extracted from yearly projections and estimates of the Population Division of the United Nations. The introduction of this variable (y_t) is aimed at verifying if the early stages of development provoke an increase of environmental degradation. As Stern (2004) stated, at the first stages of development the pollution indicators increase. The inclusion of the squared GDP per capita (y_t^2) in the right hand of regression has the objective of verifying if there is an inverted U shaped curve between income per capita and CO_2 emissions per capita. The theoretical expectation is that the coefficient of this variable is negative and significant. According to Stern et al. (1996) and Panayotou (1993), at high levels of economic growth structural changes toward information intensive industries, as well as a greater social conscience and environmental regulation, lead to a gradual decline of environmental degradation. The reason of incorporating a cubic GDP per capita (y_t^3) in the regression is to check if the environmental degradation comes back at very high levels of economic growth. Theoretically, if an inverted U shaped curve exists, the coefficient of this variable is zero. Otherwise, if such a coefficient is positive and significant, this means there is an N shaped function concerning income per capita and CO_2 emissions per capita.

The variable KP_t is a dummy that takes on the value 1 for countries that ratified the Kyoto Protocol and zero otherwise, according to the years of ratification. The agreement, which started in 2005 February, demands that more

[3] Available in: http://unstats.un.org/unsd/dnss/kf/default.aspx.

industrialized countries[4] that ratified the Kyoto Protocol commit themselves to reduce their emissions by 5.2% before 2012. These 41 more industrialized countries considered by the Agreement are located in the Northern hemisphere, except Australia and New Zealand. Theoretically, one expects the estimated coefficient for this variable to be negative. This variable has the objective of checking if the countries that are signatory of the Kyoto Protocol are reducing their CO_2 emissions before the beginning of the agreement. In this sense, this variable measures if these countries are CO_2 emission reduction prone.

The matrix of other explanatory variables X_t is composed of trade intensity variable (TI_t), energy consumption per capita (EC_t) and population density (PD_t). Formally, $X_t = [TI_t , EC_t , PD_t]$. The trade intensity variable (TI_t) is the sum of imports and exports divided by total GDP. Therefore, the objective of this variable is to demonstrate the following relationship: the greater a country's trade openness is, the smaller the environmental degradation. In the case of trade, as pointed out by Stern et al. (1996), the change of international patterns of environmental quality and structural changes within economies lead countries to specialize in activities that use less energy and natural resources. One expects theoretically that there is a negative relationship between exports and CO_2 emissions because greater trade openness would increase requirements about issues related to the environment, reducing countries' emission levels. The source of this data is the International Monetary Fund (IMF). The energy consumption per capita (EC_t) is the ratio between energy consumption and population. The energy consumption (in thousands of equivalent oil tons) comes from the UNSD. If energy is adopted everywhere and the majority of forms of utilization free pollutants, it is necessary to add a proxy to evaluate this (Agras and Chapman, 1999). So one expects theoretically that there is a positive relationship between energy use and CO_2 emissions. Lastly, the population density (PD_t) is measured by the relation between population and total geographical area for each country. The countries' total geographical areas are drawn from the databases of the Food and Agriculture Organization of the United Nations (FAO). Selden and Song (1994) suggest that in low population density countries there is less pressure to adopt strict environmental patterns and regulation. Hence this variable is aimed at demonstrating that high population density leads to a greater social conscience about environmental problems and a pressure in favor of regulation. Table II describes the variables in the empirical model.

Table II – Description of the Variables

Variable	Description	Expected Signal	Empirical Reference	Source
E_t	Carbon Dioxide (CO_2) emissions over population by country		Agras and Chapman (1999), Cole et al. (1997), Dijkgraaf and Vollebergh (2001)	UNSD, CDIAC e MDG
y_t	GDP per capita	+	Grossman and Krueger (1991), Selden and Song (1994), Kaufmann et al. (1998)	World Bank (WB)

[4] The Appendix I countries of the Kyoto Protocol are in the appendices of this paper, the dummy takes on the value one for those countries that have ratified the protocol (according to the years of ratification).

y_t^2	Squared GDP per capita	–	Grossman and Krueger (1991), Selden and Song (1994), Kaufmann et al. (1998)	World Bank (WB)
y_t^3	Cubic GDP per capita	*	Grossman and Krueger (1991), Moomaw e Unruh (1997), Arraes *et al.* (2006), Maddison (2006)	World Bank (WB)
KP_t	Kyoto Protocol dummy: value "1" for countries that ratified the agreement and "0 (zero)", otherwise	–		IEA
TI_t	Sum of imports and exports over total GDP by country	–	Shafik and Bandyopadhyay (1992), Agras and Chapman (1999), Kaufmann et al. (1998)	Internacional Monetary Fund - IMF
EC_t	Ratio between energy consumption (in equivalent oil units) and population	+	Cole et al. (1997), Stern (2002)	UNSD
PD_t	Population over the geographical area (in Km^2) by country	–	Selden and Song (1994), Shafik and Bandyopadhyay (1992)	FAO

Source: Authors'elaboration.
Note: * means "dubious".

The Moran's *I*, Geary's c and G statistics provide an indication of the degree of spatial autocorrelation. To implement these spatial autocorrelation indicators it is necessary to choose a spatial weight matrix W. In the literature, there are several examples of this type of matrix. We adopted the k-nearest neighbor matrix. To make the choice of value k less arbitrary, Baumont's procedure is adopted (Baumont, 2004). The chosen k was 2. The *I*, c and G statistics are reported in table III.

Table III. Spatial autocorrelation indicators for CO_2 emissions

Indicator	Year	Coefficient	Mean	St. Deviation	z-value	p-value
I	2000	0.481	-0.006	0.069	7.030	0.000
C	2000	0.653	1.000	0.077	-4.532	0.000
G	2000	0.025	0.012	0.002	6.864	0.000
I	2001	0.452	-0.006	0.069	6.607	0.000
C	2001	0.660	1.000	0.077	-4.451	0.000
G	2001	0.022	0.012	0.002	6.317	0.000
I	2002	0.474	-0.006	0.069	6.916	0.000
C	2002	0.650	1.000	0.076	-4.572	0.000
G	2002	0.022	0.012	0.001	6.584	0.000
I	2003	0.453	-0.006	0.069	6.620	0.000
C	2003	0.664	1.000	0.076	-4.384	0.000

G	2003	0.023	0.012	0.002	6.438	0.000
I	2004	0.450	-0.006	0.069	6.579	0.000
C	2004	0.694	1.000	0.077	-4.000	0.000
G	2004	0.022	0.012	0.002	6.362	0.000

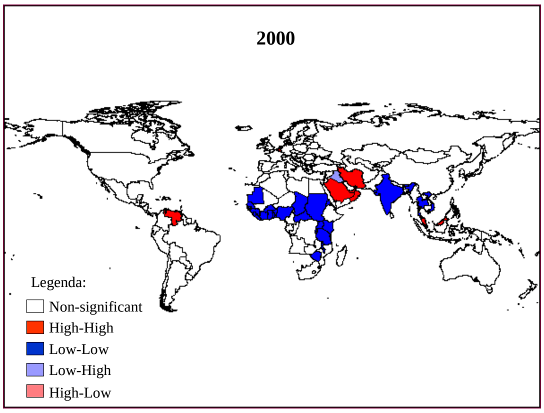
Source: authors' elaboration.

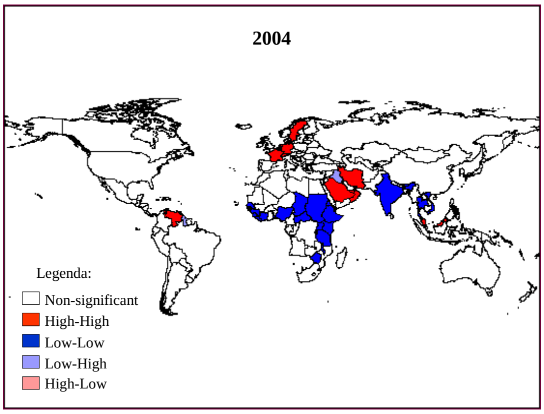
By means of three spatial autocorrelation indicators, we can reject the hypothesis of spatial random distribution of CO_2 emissions per capita across the world. All coefficients are highly significant and indicate positive autocorrelation, signaling the existence of concentration of CO_2 emissions per capita across the space. When the *I* and c statistics indicate positive autocorrelation (concentration) means that high emission per capita countries are surrounded by high emission per capita countries (High-High pattern) or low emission per capita countries are surrounded by low emission per capita countries as well (Low-Low pattern). However, the value of *G* is positive, meaning that this spatial concentration is based upon the following fact: there are predominantly high emission per capita countries that are surrounded by high emission per capita countries. Then the information of the *G* statistics refines the information about spatial concentration provided by the *I* and c, indicating the predominance of the High-High pattern.

We also adopted a local version of Moran's *I* to detect High-High (HH), Low-Low (LL), High-Low (HL) and Low-High (LH) spatial clusters.[5] In figure 3 we can observe that there are some HH clusters in Europe, a HH cluster in Middle East, a HH cluster in South America (actually, composed of only one country, namely, Venezuela), a HH cluster in Southeastern Asia. On the other hand, the LL clusters concentrate in Africa, India and Southeastern Asia. It is not possible to check the EKC hypothesis based upon only these exploratory results. It is necessary to go ahead toward the spatial econometric approach to extract more useful information.

Figure 3. LISA Cluster Map for CO_2 Emissions Per Capita

[5] For technical information about local Moran's *I*, see Anselin (1995).





Source: Authors'elaboration.

Results and Discussion

The econometric results were obtained following the procedure described in part 2. First of all, CO_2 emissions per capita (E_t) were regressed on GDP per capita (y_t), its squared value (y_t^2), its cubic value (y_t^3), a dummy for the Kyoto Protocol (KP_t), trade intensity variable (TI_t), energy consumption per capita (EC_t) and population density (PD_t) by OLS, using pooled data, but with no control for non-observable effects. Afterwards, the Hausman test indicated that the best non-observable effect model is the fixed effect model. Hence the fixed effect model was estimated by the within method. The results for these two regressions are displayed in table IV.

Table IV. Environmental Kuznets Curve (EKC) regressions

Coefficients	Pooled Data (OLS)	Fixed Effect (Within)
Constant	-0.454586* (0.1392)	-2.550838* (0.6268)
y_t	0.000200* (5.14×10^{-5})	0.001424* (0.0001)
y_t^2	-9.81×10^{-9}* (2.92×10^{-9})	-5.28×10^{-8}* (8.42×10^{-9})

y_t^3	1.07 x 10^{-13**} (4.59 x 10^{-14})	6.16 x 10^{-13*} (1.10 x 10^{-13})
KP_t	-1.252707* (0.2568)	0.004751*** (0.0400)
TI_t	0.695304* (0.1350)	-0.140282*** (0.1094)
EC_t	2.670506* (0.0476)	2.307879* (0.1374)
PD_t	7.71 x 10^{-5***} (0.0001)	-0.004695** (-2.3480)
$\bar{R}^2$	0.91	0.99
SC	1.4526	-1.0506
AIC	4.2452	2.1395
"Turning point" (max.)	US$ 10,193.68	US$ 13,484.85
"Turning point" (min.)	US$ 30,560.75	US$ 28,571.43
Jarque-Bera test	11793.7*	282033.4*
Hausman test	_____	65.46*

Source: authors' elaboration.
* significant at the 1% level.
** significant at the 5% level.
*** Not significant.
Observation: the standard deviation is in parenthesis.

For the pooled data model, all estimated coefficient values reveal as significant, except the coefficient of the population density. It is noteworthy that the trade variable presented a positive sign, not as theoretically expected. In turn, for the fixed effect model, neither trade intensity variable nor dummy for Kyoto Protocol were significant. One observes a substantial difference in terms of magnitude and sign of coefficients between the pooled data model and the fixed effect model. This can be explained by means of the control for fixed effects in the second regression. As previously checked by the Hausman test, this corroborates the hypothesis that the EKC phenomenon is influenced by the fixed effects. The relevance of including fixed effects can also be observed by the value of information criteria (AIC and SC) being significantly smaller for the fixed effect model than the pooled data model.

The residuals of the fixed effect model were checked for spatial dependence in order to control for spatial dependence. The Moran test detected spatial autocorrelation for two years (2000 and 2003) over the period under study. Therefore, in order to correct the spatial dependence in the model, some spatial components were included on the right hand in the regression.

Next several spatial models were estimated. Because of the spatial simultaneity caused by spatially lagged dependent variable (WE_t), the fixed effect model with spatial lag, spatial Durbin model were estimated by within (using IV to estimate the transformed equation instead OLS). As it is assumed that X_t is composed of exogenous explanatory variables, so WX_t is also composed of exogenous variables (namely, WTI_t, WEN_t and WPD_t). To get consistent coefficients, the spatial cross regressive model can be estimated by OLS.

The spatial error model and spatial cross regressive model with spatial error were estimated by feasible generalized least squares. To avoid the influence of extreme values on the estimations, two dummy variables have been introduced into the model from residuals of the fixed effect regression. The two standard deviation criterion was used to create these variables. Therefore, D_I is a dummy variable that takes on the unitary value if countries have residuals below the 2 SD limit. Similarly, D_S refers to countries whose residuals were above the 2 SD limit. The results are reported in table V.

Table V. Econometric Results of Spatial Models for the EKC

Coefficient	Error	Lag	Cross	Durbin	Cross + Error
Constant	-0.906497* (0.0641)	-0.798272* (0.0637)	-1.019700* (0.0942)	-0.893777* (0.0940)	-0.969118* (0.1057)
y_t	0.000568* (2.45×10^{-5})	0.000548* (2.01×10^{-5})	0.000596* (4.11×10^{-5})	0.000525* (2.86×10^{-5})	0.000589* (4.54×10^{-5})
y_t^2	$-2.30 \times 10^{-8*}$ (1.00×10^{-9})	$-2.22 \times 10^{-8*}$ (8.08×10^{-10})	$-2.24 \times 10^{-8*}$ (1.52×10^{-9})	$-2.03 \times 10^{-8*}$ (1.10×10^{-9})	$-2.21 \times 10^{-8*}$ (1.80×10^{-9})
y_t^3	$2.83 \times 10^{-13*}$ (1.23×10^{-14})	$2.73 \times 10^{-13*}$ (1.05×10^{-14})	$2.69 \times 10^{-13*}$ (1.71×10^{-14})	$2.47 \times 10^{-13*}$ (1.38×10^{-14})	$2.68 \times 10^{-13*}$ (2.10×10^{-14})
KP_t	-0.079648* (0.0194)	-0.061927* (0.0220)	-0.067232** (0.0269)	-0.063415** (0.0267)	-0.069682** (0.0725)
TI_t	-0.134104* (0.0180)	-0.122078* (0.0206)	-0.158156* (0.0159)	-0.136517* (0.0175)	-0.156392* (0.0159)
EC_t	2.643344* (0.0363)	2.664350* (0.0365)	2.640535* (0.0434)	2.679179* (0.038)	2.635650* (0.0486)
PD_t	-0.001469* (0.0003)	-0.001413* (0.0002)	-0.001773* (0.0004)	-0.001684* (0.0003)	-0.001789* (0.0004)
W_1E_t		-0.021383* (0.0039)		-0.059551* (0.0073)	
W_2u_t	-0.016879** (0.0074)				-0.030942* (0,0089)
D_I [6]	-1.454196* (0.2299)	-1.410491* (0.2475)	-1.469511* (0.1877)	-1.381131* (0.2055)	-1.464558* (0.1892)

[6] D_I is a dummy variable for lower outliers.

D_S [7]	1.494703* (0.2919)	1.541543* (0.2973)	1.471020* (0.2784)	1.514617* (0.2834)	1.472019* (0.2838)
W_Y_t			-4.12 x 10^{-5*} (1.19 x 10^{-5})	-3.03 x 10^{-5*} (1.00 x 10^{-5})	-4.83 x 10^{-5*} (1.40 x 10^{-5})
WTI_t			0.032189* (0.0073)	0.031921* (0.007024)	0.031413* (0.0075)
WEC_t			-0.009060*** (0.0192)	0.158548* (0.0191)	-0.003355*** (0.0230)
WPD_t			0.01094* (0.0001)	0.000916* (8.53 x 10^{-5})	0.001154* (0.0002)
“Turning point” (max.)	12,347.83	12,342.34	13,303.57	12,931.03	13,325.79
“Turning point” (min.)	27,090.69	27,106.23	27,757.12	27,395.41	27,487.56
Moran’s *I*	Spatial dependence in 2003	__________	Spatial dependence in 2003	Spatial dependence in 2002	__________
SC	-1.66207	-1.65957	-1.64040	-1.62793	-1.63353
AIC	-1.72435	-1.72185	-1.71966	-1.71256	-1.71845

Source: authors’ elaboration.
* significant at the 1% level.
** significant at the 5% level.
*** Not significant.
Observation: the standard deviation is in parenthesis.

By means of table IV, one observes that there is no remaining spatial dependence for the lag model and the spatial cross-regressive and error model. Actually, according to the information criteria, all spatial models present better fitness (table IV) than the pooled data model and fixed effect model with no correction for spatial dependence (table III). Using AIC and SC criteria to decide which is the best model, the choice lies in the spatial lag model as more appropriate. The analysis hereafter will focus on this model’s econometric results.

In this model, one observes that there are three channels of explanatory variables influencing the amount of CO_2 emissions per capita. A direct channel is by means of variables present in the countries themselves like GDP per capita, trade intensity, energy consumption per capita and population density. A second channel is by means of international agreements that a country may or not be signatory to. At last, the third channel is related to the spatial spillovers, that is, when the CO_2 emissions per capita inside a country are influenced by the neighbor’s emissions.

[7] D_S is a *dummy* variable for upper *outliers*.

The parameter estimates contain a wealth of information on relationships among the observations or regions. A change in a single observation (region) associated with any given explanatory variable will affect the region itself (a direct impact) and potentially affect all other regions indirectly (an indirect impact). In models containing spatial lags of the explanatory or dependent variables, interpretation of parameters becomes richer and more complicated (Lesage and Pace, 2009).

Analyzing the coefficients for variables that represent GDP per capita, it is noteworthy that the EKC estimated had an N shape. Actually, the CO_2 emissions per capita increase until reaching the first "turning point" (US$ 12,342.34) and decrease after this point as income per capita increases. When the turning point is US$ 27,106.23, the emissions come back to increase as income per capita increases. The first ascendant part of the EKC reveals that the 136 countries are within this income range. That is, more than 80% of countries analyzed, responsible for 50% of total of emissions per capita, would be still far from entering the descendent part of the curve because their income is very inferior to the turning point calculated. This result seems to corroborate the global impact of CO_2 emissions, revealing that there is little incentive for countries to take unilateral actions to reduce their emissions. Besides, the multilateral actions are being developed slowly. With more than 80% of the sample presenting a CKA monotonically crescent, it would be proper to determine emission reduction targets for an ample set of countries. According to Cole et al. (1997, p. 409), "although many nations look unlikely to meet their agreed target, the very existence of the targets at least indicates that the issue of climate change is slowly entering the political agenda".

In the sample, only 21 countries, responsible for 34% of the total emissions per capita, lie in the descendent part of the curve, that is, only 12.5% of the sample have GDP per capita above 12,342.34 and below 27,106.23. It is noteworthy that 14 out of these 21 countries are signatory of the Kyoto Protocol, such as Australia, Germany, United Kingdom, Canada, Italy, France, Spain, Netherlands, Belgium, Greece, Austria, Finland, New Zealand and Ireland. Ten nations (or 5.98% of the sample) are in the second ascendant part of EKC, that is, have a GDP per capita above 27,106.23 and are responsible for 16% of emissions per capita, namely, USA, Switzerland, Sweden, Norway, Luxembourg, Iceland, Island, Ireland, Denmark and Japan. The positive coefficient that accompanies the variable y_t^3 suggests that CO_2 emissions per capita eventually come back to increase, revealing that the U shaped relationship can be only temporary. All European countries in this part of the curve, beside Japan, ratified the Kyoto Protocol. Using only sixteen countries, Moomaw and Unruh (1997) found an N shaped EKC for CO_2 emissions per capita. The turning point estimated by the authors was US$ 12,813, a value near that found in this paper. Using a 34 country sample, the turning point found by Agras and Chapman (1999) was US$ 13,630 for CO_2 emissions per capita. The findings suggest that the differences among turning points for emissions per capita are not so big as believed by Selden and Song (1994). It is worth pointing out that the 167 country sample adopted here is much larger than any sample ever used in the EKC literature.

A noteworthy result is the coefficient presented by the Kyoto Protocol dummy variable, which was revealed to be negative and significant, suggesting that countries that ratified the Protocol before 2004 would already be causing a reduced effect on emissions. In this case, although the Protocol only started in 2005, February, this variable revealed that the countries that ratified the agreement are already contributing to reduce their CO_2 emissions per capita, even though this reduction is small (0.06 metric tons). If environmental improvements are also provoked by public policy changes, growth and development can not substitute these policies. The absence of vigilance in any region or country leads to the situation that there is always the possibility of greater production causing greater consumption of scarce resources (Torras and Boyce, 1998).

The fact of most countries lying in the first ascendant part of the curve raises the discussion, once again, about the role that developed countries should play in international agreements for limiting emissions. If economic growth leads to a reduction of CO_2 emissions after a certain income level, in the case of global EKC estimated here, the effect of this reduction is yet very small because some nations would simply be in income ranges that would favor this decrease.

In the case of developing countries, an important question would be that the CO_2 reduction targets should take into account each country' responsibility in the total emissions at the global level. In the period under study, some developing countries have high emissions per capita, such as China, South Korea, Mexico, South Africa and Venezuela. It is necessary that these countries also commit themselves to the reduction of greenhouse gases so as not to have only a displacement of pollutant industries from the more developed countries to these nations. However, the discussion about CO_2 reduction targets lies in the fact that developing countries are largely responsible for the total stock of carbon in the atmosphere and, thereby, the reduction targets should be focused much more on these countries. Besides, the fact of the USA being the most responsible for CO_2 emissions in the world and its refusal to ratify the Kyoto Protocol can be exerting an influence toward the increase of emissions and consequently for the N shaped EKC.

It is noteworthy that the coefficient of the spatially lagged dependent variable (W_1E_t) is negative and significant. It indicates that a neighbors' emissions increase has a negative effect on CO_2 emissions per capita. This effect is reduced by about 0.02 metric tons of carbon so the coefficients of other variables are little affected by spatial lag. This variable seems to suggest that CO_2 emissions follow a dispersion pattern and not a concentration pattern. This could have happened due to the fact of the regression control for other explanatory variables, as well as the residuals being correlated spatially in a negative fashion. More importantly, nevertheless, is that the variable is correcting the spatial dependence problem existent in the data.

Another reason for this dispersion of CO_2 emissions across the countries can be the free-riding problem. In the case of GEE (Greenhouse Effect Emissions), the cost of an agents' choices are imposed on all agents, dispersed around the world. Besides, the eventual benefits accruing from the emissions reduction are distributed among them. In this manner, an individual agent does not have incentives to invest in the reduction of emissions and, rationally, would wish to expect that the other agents reduced their emissions in order to participate only in the resulting benefits (Brauch, 2007). Shafik (1994) adverts that this problem worsens because of the uncertainty about the magnitude of the benefits accruing from an emission reduction, as well as because of the period in which such benefits would be reached.

The dispersion can also be a result of policies that regulate only the developed countries' CO_2 emissions, implying that the neighboring developing countries increase their emissions due to the displacement of carbon intensive activities from the developed countries toward their economies.

Concerning the other explanatory variables, in the case of trade intensity, TI_t, its coefficient is negative and significant, as theoretically expected. This means the following: the larger the trade intensity is, the smaller the CO_2 emissions are. This result corroborates the results found by Grossman and Krueger (1991) and Poon et al. (2006). An important factor is the firms' exposure to international competition, which leads to the incorporation by these firms of a more environmentally correct attitude. The coefficient of the variable EC_t is positive and highly significant, as theoretically expected. If energy consumption has increased along the income range of the sample, despite regular advances in energy efficiency, it is not surprising that the same thing takes place with CO_2 emissions (Cole et al., 1997). In the case of population density, Selden and Song (1994) suggest that in countries with low density there will be less pressure to adopt strict environmental patterns and the correspondent emissions from transport activities will be larger. The negative and significant coefficient for the variable PD_t confirms this expectation, showing that more population density causes a reduction of CO_2 emissions per capita. This relationship occurs mainly because the society starts demanding more quality and environmental regulation and, thereby, starts applying pressure for a cleaner environment.

An issue which has not been addressed in the literature is the endogeneity problem or "reverse causality" that could exist between the CO_2 emissions per capita and GDP per capita and/or the CO_2 emissions per capita and the dummy variable for the Kyoto Protocol. The point would be that besides greater GDP per capita causing more CO_2 emissions, a country with high emissions might cause greater GDP per capita. In the case of the dummy for the Kyoto Protocol, the issue would accrue because not only are the countries that ratified the Protocol causing the reduction of emissions, but the emissions of these countries might be low before these nations ratified the Protocol. To check the existence of this endogeneity issue the Durbin-Wu-Hausman test[8] for these variables was done. The null hypothesis of exogeneity was not rejected at the 1% level both for GDP per capita variable and dummy variable for the Kyoto Protocol.

Final Considerations

This study analyzed the relationship between income per capita and CO_2 emissions per capita with panel data from 167 countries over the period 2000-2004. In methodological terms, a sophisticated fixed effect model with spatial dependence was constructed to estimate the global EKC. The dependent variable was regressed on GDP per capita, squared GDP per capita, cubic GDP per capita, trade intensity, energy consumption per capita, population density and a dummy to indicate countries that ratified Kyoto Protocol.

By extending the model including the cubic form of GDP per capita one concludes that continuous income increase does not guarantee the continuous improvement of environmental quality, provided that the relationship between EKC and CO_2 emissions is just temporary because an N shaped EKC was found. This means that the relationship between income and emissions is not automatic

[8] The table reporting the Durbin-Wu-Hausman tests is in the appendix of this paper.

and, thereby, possibilities for designing public policies and international agreement accrue as a form of promoting the environmental improvement, as suggested by Grossman and Krueger (1995) and Stern (2004).

The turning points calculated were US$ 12,342.34 and US$ 27,106.23. From this econometric result, it is noteworthy to shed light on some important issues. For instance, the fact that 80% of the sample do not have income per capita above the first turning point calculated, that is, the majority of countries would lie in the ascendant part of the curve. This seems to corroborate the global impact of CO_2 emissions, revealing that there is little incentive for nations to take unilateral actions in order to reduce their emissions.

Other important issue is about the negative and highly significant coefficient for the dummy variable indicating the countries that ratified Kyoto Protocol. The commitment of these countries to effectively reduce their emissions began in 2008. However it seems that these countries have already begun to reduce their emissions per capita. Actually, this variable can be capable of capturing the country’s proneness to reduce emissions. This result shows that the potential relevance of international agreements in the reduction of global amount of emitted dioxide carbon. Therefore, economic growth itself cannot substitute public policies that try to reduce CO_2 emissions.

Although international agreements can be important in the reduction of greenhouse gases, the emissions need to be targeted according to each country’s responsibility in the total amount of emissions. Only sixty countries are responsible for about 75% of the total emissions over the period under study. These countries lie mainly in Europe (38 countries), North America (Canada and USA), Asia (14 countries), Africa (Libya and South Africa), in Central America (Trinidad and Tobago), South America (Venezuela) and Oceania (New Zealand and Australia). Of these countries, only the outliers, represented by USA, Aruba, Australia, Bahrain, Brunei, Canada, Kuwait, Luxembourg, United Emirates, Trinidad and Tobago are responsible for more than 30% of the total amount of CO_2 emissions. Consequently, any attempt to impose a regulation mechanism for the global environmental management should observe these distribution effects.

One can conclude that a global EKC for CO_2 emissions per capita hardly reaches the descendent part of the curve unless multilateral public policies are implemented. The coefficient of the variable indicating the countries that ratified Kyoto Protocol suggests multilateral policies can help to reduce CO_2 emissions. However, it is necessary that more countries commit themselves in this reduction, since the effect of this variable was revealed to be small. Developing countries also should adopt targets according to their responsibility in the total amount of emissions.

In sum, the main conclusion of this paper is that economic growth does not guarantee the cure for the world’s environmental problems. Proper multilateral environmental policies can have a fundamental role in the reduction of GEE emissions on the Earth.

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APPENDIX

Countries that take part in Appendix I of the Kyoto Protocol

Countries	Ratification year	% of the total 1990 CO_2 emissions
USA*	-------------	35.04
Russia	2004	17.50
Australia	2007	1.86
Croatia	2007	0.00
Liechtenstein	2004	0.00
Monaco*	----------------	0.00
Germany	2002	6.96
Japan	2002	6.91
Ukraine	2004	4.40
United Kingdom	2002	4.20
Canada	2002	3.34
Italy	2002	2.91
France	2002	2.62
Polonia	2002	2.29
Check Republic	2001	2.06
Spain	2002	1.59
Netherlands	2002	1.48
Romania	2001	1.22
Belgium	2002	0.87
Bulgaria	2002	0.59
Greece	2002	0.57
Hungry	2002	0.47
Denmark	2002	0.39
Austria	2002	0.39
Sweden	2002	0.38
Finland	2002	0.37
Switzerland	2003	0.31
Portugal	2002	0.31
Norway	2002	0.24
New Zealand	2002	0.20
Lithuania	2003	0.19
Ireland	2002	0.18
Luxembourg	2002	0.08
Estonia	2002	0.07
Island	2002	0.02
Latvia	2002	0.00
Slovaquia	2002	0.00
Slovenia	2002	0.00
Total		100.00

* Countries that do not ratified the Kyoto Protocol.

Table of Durbin-Wu-Hausman test

Test of endogeneity of GDP per capita			
Coefficient	1.43875	p-value	0.23034
Test of endogeneity of the Kyoto Protocol dummy			
Coefficient	6.44280	p-value	0.01114