A panel estimation of the relationship between income, electric power consumption and CO2 emissions

Gianni Bellla and Carla Massidda and Ivan Etzo

September 2010

A panel estimation of the relationship between income, electric power consumption and CO_2 emissions

by

Giovanni Bella, Carla Massidda and Ivan Etzo

University of Cagliari
Department of Economics
Viale S. Ignazio, 17, 09123 - Cagliari (Italy)

Abstract

This paper aims to give a contribution on the still questioned bell-shaped relationship between carbon dioxide polluting emissions and economic growth, which is commonly known in the literature as the Environmental Kuznets Curve hypothesis. In particular, it develops a panel analysis for a group of 77 countries, including 22 OECD and 55 NON-OECD units, over the period 1971-2006. We specify the estimated model by taking into account the role of electric power consumption and compare the performance of alternative panel estimators for a quadratic and cubic specification of the empirical model. Our findings seem to go in favor of the *EKC* relationship for the entire sample. However, this outcome is not confirmed when moving the analysis at sub-sample level where results highlight a non homogeneous picture across different groups of nations.

Keywords: Panel analysis, Environmental Kuznets Curve, CO_2 emissions and Energy use
JEL classification: C33, Q43, Q54

1. Introduction

Over the last two decades, the relationship between economic growth and environmental degradation has been an intensely debated issue. It has been commonly argued that an inverted U-shaped relationship between environmental quality and per capita income might exist, which is known in the literature as the Environmental Kuznets Curve (EKC) hypothesis (for an extensive overview, *cfr*. *inter al*., Copeland and Taylor, 2004; Dinda, 2004; Stern, 2004). This hypothesis has been firstly advanced in the seminal paper of Grossman and Krueger (1995) where it was provided the empirical evidence that economic growth seems to impinge on environmental quality at the initial stages of development, though, after a certain threshold is passed, it leads to a subsequent amelioration of environmental conditions.

After the Grossman and Krueger (1995) contribution, a sizeable literature has sparked efforts to justify the *EKC* hypothesis, for various indicators of environmental degradation. In general, it seems that only for some local pollutants, such as sulfur oxides (*SOx*), there is evidence of an *EKC*. In this case, robust empirical evidence of an inverted U-shaped relationship is more likely to be found since local pollutants lead to a more direct impact on individuals' health at a national level and greater demand for their reduction is registered as national income grows over time (*cfr*., Stern and Common, 2001). Unfortunately, the same is not valid for global pollutants such as carbon dioxide (CO_2) emissions which mostly exhibit a monotonically increasing (or decreasing) evolution instead (*cfr*. *inter al*., Shafik, 1994; and Holtz-Eakin and Selden, 1995). It turns out that empirical evidence supporting the existence of an inverted U-shaped relationship between CO_2 emissions and income is quite scant and either refers to high income countries only or sometimes suffers the emergence of turning points well off a feasible range.[1]

These puzzling outcomes seriously worry environmental decision makers desperately seeking to find a bell-shaped evolution for CO_2 emissions, which are commonly referred to as the main determinant of global warming. This is the reason why the empirical validation of *EKC* is still so questioned and under investigation.

Among others, the appropriate way to mathematically model the *EKC* evolution is one of the most debated issues. Several papers, for instance, have tested alternative polynomial functional forms to check whether a bell-shaped or a *N*-shaped curve better describe the evolution of some pollutant

---

[1] *Cfr.* Aslanidis (2009), Mazzanti and Musolesi (2009) for exhaustive discussions on the issue.

indicators as income grows (*cfr*., *inter al*., Grossman and Krueger, 1995; Dinda *et al*., 2000). On the contrary, another strand of literature suggests that this type of relationship might not be appropriate to model CO_2 emissions and focuses on more flexible specifications compared to the standard polynomial functional forms (*cfr*., *inter al*., Beltratti, 1997; Azomahou *et al*., 2006; Galeotti *et al*., 2006).

Another limitation recognized to this literature is that many of the studies consider the relationship between economic growth and environmental degradation in a bivariate framework and thus suffer from omitted variables bias. To overcome this limit, a strand of literature has recently suggested to investigate the relationship between economic growth, CO_2 emissions and energy consumption. This new line of research takes origin from the marriage of the *EKC* studies with the parallel literature that focuses on the relationship between economic growth and energy consumption (*cfr*., *inter al*., Richmond and Kaufmann, 2006; Apergis and Payne, 2009; Lean and Smith, 2010). This link can be justified since higher energy consumption is needed to foster sustained economic growth. At the same time, however, higher levels of economic development can influence the efficient utilization of energy in the production processes. Therefore, it could exist a bi-directional causal relation between these two variables. On this point, the literature is still inconclusive (Ferda, 2009).

A further relevant criticism is concerned with the tendency of recent empirical studies to use panel data models to estimate a one-fit-for-all relationship to characterize the shape of the income-pollution evolution. This relationship is probably too difficult to be found, even though for some countries of the panel specific tests could give evidence of individual (country-specific) *EKC*, which might not appear if a global (panel) analysis is conducted (*cfr*., De Bruyn et al., 2008). Moreover, even when a one-fit-for-all relationship is found, the estimation of the income level at which emissions reach their peak is somehow misleading, since it indicates a level higher than the current per capita income of most countries or out of the observed range (*cfr*., *inter al*., Selden and Song, 1994; Richmond and Kaufmann, 2006). According to a very recent interpretation, it has been advanced the idea that reliability of turning points estimate may depend on whether the sample is globally representative or not. This issue has been mainly addressed by means of heterogeneous panel estimation techniques which, differently from traditional homogeneous estimators, tend to reduce the restrictions imposed to the estimated coefficients of the model.[2]

[2] Two more concerns are related to the possibility of spurious results due to the presence of non-stationary time series and to spatial dependence in emissions across countries.

With this paper we intend to give a contribution to the aforementioned debate. To this end, we develop a panel analysis concerning the existence of an inverted U-shaped relationship between carbon dioxide emissions and per capita income for OECD and NON-OECD countries, over the period 1971-2006. In particular, we both specify the estimated model by taking into account the role of electric power consumption and compare the performance of alternative panel estimators for a quadratic and cubic specification of the empirical model.

The contribution is organized as follows. Section 2 presents the alternative panel methodologies that commonly characterize the empirical literature related to the *EKC* hypothesis. Section 3 presents our research strategy and some descriptive statistics of the variables considered in the empirical model. Then, Section 4 highlights the results. Finally, Section 5 draws some conclusions.

2. Panel estimation methods

According to a very recent approach, it has been advanced the idea that, when the *EKC* relationship is studied in a panel context, estimation biases and reliability of turning points may depend on whether the sample is globally representative or not (List and Gallet, 1999). This argument is strictly correlated to the type of econometric models most often implemented in this strand of literature.

The simplest model on the issue imposes the same *EKC* to all units of the sample, i.e. assumes constant coefficients across units. A second and less restrictive approach allows the regression intercept to vary across countries. This approach employs standard homogeneous estimators, such as fixed (*FE*), or random effects models (*RE*), and estimates a relationship of the following form:

$$(1)\quad y_{it} = \alpha_i + \sum_{j=1}^{k} \beta_j x_{itj}$$

where y_i is pollution per capita in country i (i = 1…m) and x_{ij} is the explanatory variable j in country i.

Usually empirical analysis focuses on a standard representation of the model in equation (1) where the only explanatory variable is income per capita. In such a case, the general econometric model becomes:

(2) $y_{it} = \alpha_i + \beta_1 x_{it} + \beta_2 x_{it}^2 + \beta_3 x_{it}^3 + \varepsilon_{it}$

where variables are measured in natural logarithms so that all betas can be interpreted as elasticities. Under $\beta_3 = 0$, a restricted model is obtained from eq. (2). In this case, if $\beta_1 > 0$, $\beta_2 < 0$, a quadratic, bell-shaped, relationship exists, as predicted by the standard *EKC* hypothesis. The underlying assumption states that environmental degradation starts declining once the same level of income per capita for all countries of the sample is reached, even though the highest degradation level can differ across units. The estimated turning point is:

(3) $x^* = \exp(-\beta_1 / 2\beta_2)$

Conversely, the unrestricted model in eq. (2), with $\beta_3 \neq 0$, represents a cubic polynomial (Dinda, 2004). In this case, a third order polynomial functional form with $\beta_3 > 0$ allows us to test for the presence of a *N*-shaped curve, which suggests the possibility that the slowdown of pollutants associated with income growth might be rather volatile and barely temporary. On the contrary, when $\beta_3 < 0$, the presence of an inverted *N* curve might easily suggest an empirical support in favor of a bell-shaped evolution for CO_2, particularly when the income turning point associated with the minimum pick is low and the maximum lies within an economically feasible range.

The general formulation corresponding to the estimated turning points for the cubic polynomial becomes:

(4) $x^* = \exp((-\beta_2 \pm \sqrt{\beta_2^2 - 3\beta_1\beta_3}) / 3\beta_3)$

The theoretical assumption expressed in eq. (2) is not shared by a recent strand of empirical literature pointing out that the assumption of high degree of homogeneity across countries is perhaps unrealistic. Conversely, it would appear more reasonable to assume some degree of cross-countries heterogeneity in the slope coefficient. This idea can be incorporated in a random coefficients (*RC*) model as expressed by the following equation (*cfr. inter al.*, Koop and Tole, 1999; Cole, 2005; Figueroa and Pasten, 2009):

(5) $y_{it} = \alpha_i + \beta_{1i} x_{it} + \beta_{2i} x_{it}^2 + \beta_{3i} x_{it}^3 + \varepsilon_{it}$

where β_{ij}, with j = 1,2,3 is assumed to be drawn from some common distribution $\beta_i = \beta + v_i$, with $E(v_i) = 0$, $E(v_i v'_i) = \Omega$ and $E(v_j v'_i) = 0$ for $i \neq j$. According to this definition, β represents the average *GDP*-pollution relationship, while v_i captures the difference that each country can exhibit from this average. If Ω is small, β can be considered an expression of the *GDP*-pollution relationship for the entire sample. Conversely, if Ω is large, then cross-country heterogeneity is large, and it becomes unsuitable to assume that β is the same for all units. The estimated turning points are thus:

$$(6)\; x_i^* = \exp(-\beta_{1i} / 2\beta_{2i})$$

and

$$(7)\; x^* = \exp((-\beta_{2i} \pm \sqrt{\beta_{2i}^2 - 3\beta_{1i}\beta_{3i}}) / 3\beta_{3i})$$

for the quadratic and cubic specification, respectively.

The *RC* model, along with other estimators such as the Mean Group (Pesaran and Smith, 1995) and the hierarchical Bayes approach (Hsiao *et al*., 1999), are classified as heterogeneous. Their use, is suggested when the time dimension of the analysis increases and a high degree of heterogeneity characterizes the panel. However, as highlighted by recent research, it can happen that the efficiency gains from pooling overcome the costs (Baltagi *et al*. 2000, 2002, 2004). In light of this, an intermediate estimator such as the Pool Mean Group (*PMG*), proposed by Pesaran *et al*. (1999), is often suggested (*cfr*. Martinez-Zarzoso and Bengochea-Morancho, 2004). Differently from the Mean Group (*MG*), the *PMG* estimator, within a panel cointegrated framework, allows intercepts, short-run coefficients and error variances to differ freely across countries, but it holds constant the long-run coefficients.

According to the updated empirical research, it appears that the choice of one estimator instead of another is not an easy task. It seems that for non-homogeneous groups of countries, results are sensitive to the degree of heterogeneity assumed by the econometric model. In this respect, it is difficult to define a priori the underpinnings behind the homogeneity issue across data in a sample. Different criteria can be used to pool countries altogether. For example, using the *GDP* as a choice variable can be slightly misleading and not conclusive, for other social and political aspects might best capture the common structure of the different economies being analyzed. The recent contribution of Mazzanti and Musolesi (2009), for instance, compares the performance of a set of homogeneous, heterogeneous, shrinkage and spatial panel estimators. They consider three groups of countries, namely the so-called Umbrella group, the EU-north countries and the EU-south countries, depending on the different policies they adopted to comply with the environmental commitments addressed in the Kyoto Protocol. They find that differences between homogeneous and heterogeneous estimators are relevant for all groups except the EU-north one, that is mainly composed of those countries that supported the Kyoto targets since the beginning.

3. Research strategy and data description

3.1 *Research strategy*

In this paper we aim at giving a new contribution to the *EKC* literature by addressing contemporaneously two of the main issues arisen along the recent literature on this issue. On the one hand, to correct for possible omitted variable biases, we study the relationship between CO_2 emissions and economic growth considering electric power consumption (*EPC*) as an additional explanatory variable intended to capture the dynamic of energy use. Accordingly, our econometric model can be written as follows:

(8) $co_{2,it} = \alpha_i + \beta_1 gdp_{it} + \beta_2 gdp^2_{it} + \beta_3 gdp^3_{it} + \beta_4 epc_{it} + \varepsilon_{it}$

where lower letters case denote natural logarithms of variables.

On the other hand, to control for the sensitivity of empirical results to the chosen econometric model, we compare the performance of alternative panel estimators assuming different degree of heterogeneity within the sample. At this scope, we consider five estimation models, namely the *FE*, *RE*, *PMG*, *MG* and the *RC*. The *RC* model is implemented using the Swamy and Metha (1975) estimator that allows to obtain slope coefficients for each country, so that country specific turning points can be individually predicted.

We divide our research agenda into three main steps. As first step, we study the long-run properties of the three variables involved in the analysis. To this end, we implement two panel unit root tests developed by Im *et al*. (2003) and Maddala and Wu (1999), hereafter named *IPS* and *MW*, respectively. The first is based on the mean of the individual Dickey-Fuller t-statistics of each unit in the panel. It assumes non-stationarity under the null hypothesis and is consistent under the alternative that only a fraction of the series is stationary. The second is performed using a Fisher statistics and assumes non-stationarity under the null hypothesis against the alternative that at least one series is stationary. If the series will prove to be non stationary but integrated of order one we will apply the recent residual-based panel cointegration tests developed by Westerlund (2007). In fact, in case of non cointegration only the *PMG* estimates will be consistent, while the results from the other estimators will be spurious.

The second step of our work consists in estimating eq. (8) under the restriction $\beta_3 = 0$, which implies that the quadratic functional form is the first *EKC* relationship under our consideration. For this model, results gathered through the five panel estimators are provided and compared.

As third, and final step, we repeat the same analysis for the cubic functional form corresponding to the unrestricted eq. (8).

The described analysis involves a large panel of countries drawn from the World Bank dataset (WDI, 2010) over the period 1971-2006. It consists of 77 units including 22 OECD and 55 NON-OECD countries. Accordingly, each estimation is carried out three times, that is for the Full sample and for the two sub-samples. A detailed description of our dataset is provided in the following section.

3.2 *Data description*

The primary data employed in this paper are the annual CO_2 emissions measured in metric tons per capita, the *GDP*, constant at year 2000 prices and expressed in US dollars and per capita terms, and the electric power consumptions (*EPC*), expressed in Kwh per capita.

The following Tables 1-3 provide an overview of some descriptive statistics for each single variable within our dataset over the period 1971-2006. As it appears, given the double dimension of our panel data, we calculate our statistics along two directions corresponding to the within and the between dynamics of each variable. Specifically, we are interested in decomposing the total variance of each determinant into the within variance (*the difference between the individual observation and its mean*) and the between variance (*the difference between the individual mean and the total mean computed for all individuals and all periods*).

Table 1. Summary Statistics – CO_2

Sample		Mean	Std. Dev.	Min	Max	Obs
FULL	*overall*	4.96	5.40	0.02	40.29	N = 2772
	between		5.26	0.06	26.11	n = 77
	within		1.37	-3.84	19.14	T = 36
OECD	*overall*	10.02	5.59	1.28	40.29	N = 792
	between		5.43	2.44	26.11	n = 22
	within		1.74	1.22	24.20	T = 36
NON-OECD	*overall*	2.94	3.75	0.02	25.38	N = 1980
	between		3.59	0.06	15.72	n = 55
	within		1.18	-4.53	12.59	T = 36

Table 1 shows the summary statistics referred to CO_2 emissions for the full sample and the two sub-samples (OECD and NON-OECD). The mean CO_2 value ranges from 2.94 for NON-OECD countries to 10.02 in the OECD ones, which implies a in-between value of 4.96 for the full sample. The volatility of the series, measured by the Standard Deviation, takes its lowest value in the NON-OECD sub-sample (3.75); for the OECD sub-sample it increases to 5.59, and at the full sample level it corresponds to 5.40. In summary, NON-OECD countries, on average, both exhibit the lowest level of CO_2 emissions and the least dispersion degree, which also means a lower heterogeneity within this group of countries.

Table 2. Summary Statistics – *EPC*

Sample		Mean	Std. Dev.	Min	Max	Obs
FULL	*overall*	3142.92	4498.22	5.81	31328.39	N = 2772
	between		4304.22	33.77	21435.57	n = 77
	within		1393.41	-6875.72	17447.81	T = 36
OECD	*overall*	7500.85	5099.55	236.76	25594.95	N = 792
	between		4853.73	928.29	21435.57	n = 22
	within		1867.93	149.83	13334.22	T = 36
NON-OECD	*overall*	1399.75	2701.24	5.81	31328.39	N = 1980
	between		2465.81	33.77	17023.50	n = 55
	within		1150.66	-8618.89	15704.64	T = 36

Table 2 highlights the same summary statistics for *EPC*. As we can see, the mean value ranges from 1399.75 in the NON-OECD countries to 7500.85 in the OECD ones, with a in-between value of 3142.92 for the full sample. According to the Standard Deviation, also for *EPC* the least volatility is registered in the NON-OECD sub-sample (2701.24). Dispersion rises in the full sample (4498.22), while it displays the highest value in the OECD sub-sample (5099.55). According to Table 2, again NON-OECD countries exhibit the lowest mean and dispersion degree.

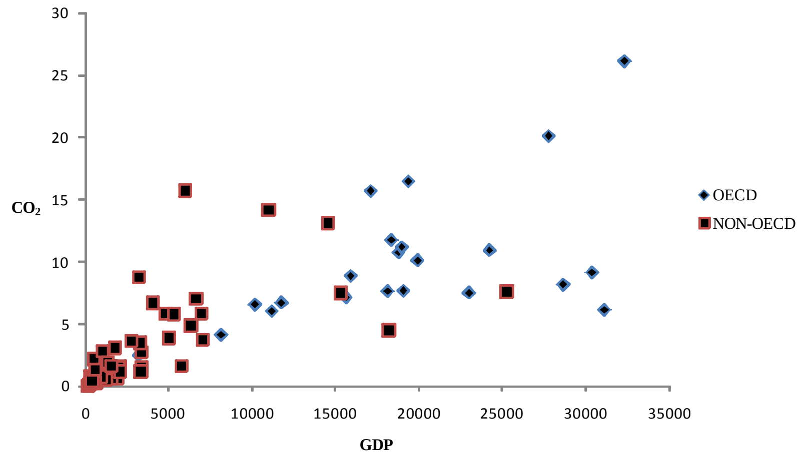
Finally, Table 3 reports the summary statistics for per capita *GDP*. We find that the mean value ranges from 3528.60 in the NON-OECD sub-sample to 18952.26 in the OECD one, and corresponds to 7939.95 in the full sample. With respect to the Standard Deviation, again NON-OECD countries reveal a lower degree of dispersion (5197.02). Not surprisingly, these groups of countries have the lowest average income per capita.

Table 3. Summary Statistics – *GDP*

Sample		**Mean**	**Std. Dev.**	**Min**	**Max**	**Obs**
	overall	7936.95	9496.79	80.62	54405.83	N = 2772
FULL	between		9066.13	179.55	31607.02	n = 77
	within		3003.76	-6038.96	30735.75	T = 36
	overall	18952.26	8842.04	2141.94	54405.83	N = 792
OECD	between		7575.26	3212.60	31607.02	n = 22
	within		4830.76	4976.36	41751.07	T = 36
	overall	3528.60	5197.02	80.62	36884.18	N = 1980
NON-OECD	between		4911.72	179.55	25272.57	n = 55
	within		1817.45	-8272.20	17651.24	T = 36

With the aim of giving more information on our dataset, it can be also interesting to analyze the possible existing correlation between the variables used to estimate our model. Fig. 1 shows the joint correlation of the average levels of CO_2 and *GDP* in the two sub-samples under analysis. As expected, we observe that most of the NON-OECD countries are lagging behind with respect to the OECD ones. Moreover, it seems that, despite some outliers, observations for the NON-OECD group are more likely to capture a monotonic increasing relationship between income and pollution. The same seems not to apply for the OECD countries, whose observations are more spread and might very well capture both a bell-shaped or a N-shaped distribution. Overall, the full sample observations seem to match with the inverted U-shaped evolution suggested by the standard *EKC* hypothesis.

Figure 1. *CO_2-GDP* relationship for the full sample



4. Results

4.1 *Unit root and panel cointegration analysis*

We start this section presenting in Table 4 the main outcomes of our unit root analysis. As previously anticipated, we have considered two panel unit root tests, that is *IPS* and *MW*. For all the variables in levels, both the *IPS* test and the *MW* test provides evidence of non-stationarity. Results from the tests in first difference show that all variables are integrated of order one, consequently panel cointegration tests can be employed to study the long run equilibrium process.

Table 4. Panel unit root tests

Unit Root tests	***co_2***	***gdp***	***epc***
Level			
IPS test	-0.35	0.52	2.92
P-val	*0.36*	*0.70*	*0.99*
MW-Fisher ADF	152.94	178.84	120.01
P-val	*0.51*	*0.08*	*0.98*
First difference			
IPS test	-16.36	-9.59	-12.01
P-val	*0.00*	*0.00*	*0.00*
MW-Fisher ADF	597.56	405.85	514.70
P-val	*0.00*	*0.00*	*0.00*

Notes: All unit root tests were performed with trend and 2 periods lags. The table reports W[t-bar] statistics for IPS tests and chi2 statistics for MW-Fisher.

In this respect, as anticipated in the previous section, we apply the panel cointegration tests developed by Westerlund (2007). Differently from the other residual-based cointegration tests (cfr. Pedroni, 2004), these tests do not imply the common factor restriction, whose failure can seriously reduce the power of the tests. The tests are applied on all the different specifications that will be estimated in the next subsection. The results in Table 5 show evidence of cointegration for the FULL sample and for the NON-OECD sample in the quadratic specification. For all the other specifications the p-values do not reject the null that the residuals do not contain a stochastic trend, thus the variables do not cointegrate. It is worth to point out that for the sole *PMG* estimator the estimates are reliable even in presence of variables which are not stationary (Pesaran and Smith, 1995).

Table 5. Panel cointegration tests

Quadratic specification - FULL				***Cubic specification - FULL***			
Statistic	**Value**	**z-value**	**p-value**	**Statistic**	**Value**	**z-value**	**p-value**
Gt	-1.98	-2.32	0.01	Gt	-2.07	-0.78	0.22
Ga	-6.26	2.18	0.99	Ga	-5.64	5.23	1.00
Pt	-14.06	-1.91	0.03	Pt	-14.91	-0.57	0.28
Pa	-5.25	-1.36	0.09	Pa	-5.67	0.53	0.70
Quadratic specification - OECD				***Cubic specification - OECD***			
Statistic	**Value**	**z-value**	**p-value**	**Statistic**	**Value**	**z-value**	**p-value**
Gt	-1.97	-1.21	0.11	Gt	-2.29	-1.41	0.08
Ga	-5.86	1.47	0.93	Ga	-5.04	3.19	1.00
Pt	-7.93	-1.33	0.09	Pt	-8.53	-0.75	0.23
Pa	-4.75	-0.36	0.36	Pa	-4.25	1.20	0.89
Quadratic specification - NON-OECD				***Cubic specification - NON-OECD***			
Statistic	**Value**	**z-value**	**p-value**	**Statistic**	**Value**	**z-value**	**p-value**
Gt	-1.98	-1.98	0.02	Gt	-1.98	-0.02	0.49
Ga	-6.42	1.66	0.95	Ga	-5.89	4.16	1.00
Pt	-11.86	-1.60	0.06	Pt	-12.60	-0.48	0.32
Pa	-5.27	-1.18	0.12	Pa	-5.76	0.36	0.64

4.2 *Estimates*

We move then to the second step of the empirical analysis. Results are presented in Table 6 which illustrates the estimates for the model specifications presented in eq. (8), under the restriction β_3 = 0. The main outcomes can be summarized as follows

For the full sample, it is interesting to note that the two homogenous estimators give similar coefficients that are statistically significant and with the expected sign. The associated turning points appear to be feasible, in that they are inside the range of the observed values (80-54405$). Conversely, the *RC* estimator does not provide statistically significant results. The intermediate estimator provides evidence for an inverted U-shaped curve with a feasible turning point.

Table 6. The quadratic specification of the model

		FE		***RE***		***RC***		***PMG***	
Sample	**Variable**	**Coeff**	**t**	**Coeff**	**t**	**Coeff**	**z**	**Coeff**	**z**
FULL	*gdp*	1.785***	21.53	1.813***	22.16	3.088	0.65	1.487***	11.15
	gdp^2	-0.087***	-17.47	-0.086***	-17.56	-0.143	-0.41	-0.075***	-10.16
	epc	0.244***	18.94	0.242***	18.91	0.161*	2.47	0.375***	18.46
	cons	-9.407***	-28.34	-9.646***	-29.22	-15.043	-0.88		
	Obs	2771		2771		2771		2618	
	Hausman	chi2(3)=67.12							
	TP	28983.57		35712.61				20197.89	
OECD	*gdp*	7.239***	12.89	7.210***	13.21	0.465	0.11	-1.408*	-2.51
	gdp^2	-0.367***	-13.62	-0.366***	-13.94	-0.039	-0.18	0.046	1.66
	epc	0.117**	2.81	0.121**	2.98	0.216	1.62	0.763***	25.84
	cons	-34.387***	-13.06	-34.272***	-13.4	-0.362	-0.02		
	Obs	792		792		792		748	
	Hausman	chi2(3)=5.34		Valid					
	TP	18987.38		18971.34				4431939.36	
NONOECD	*gdp*	1.335***	12.43	1.353***	12.73	3.485	0.54	1.311***	7.95
	gdp^2	-0.051***	-7.29	-0.052***	-7.41	-0.148	-0.31	-0.056***	-5.62
	epc	0.221***	15.03	0.223***	15.28	0.155*	2.07	0.321***	12.66
	cons	-8.075***	-19.95	-8.194***	-20.17	-18.087	-0.8		
	Obs	1979		1979		1979		1870	
	Hausman	chi2(3)=20.86							
	TP	438710.61		473962.35				121219.37	

Notes: the Hausman specification test assumes that the estimates from the random effects models are consistent under the null hypothesis. *Stars* denote p-values as follows: * $p<0.05$; ** $p<0.01$; *** $p<0.001$. According to the test, the *RE* is valid for the OECD countries sub-sample, whilst the *MG* estimates are always rejected and for this reason results are omitted Results are available upon request.

Moving to the OECD countries, we can notice that again the homogeneous estimators give similar and significant coefficients with the expected signs and turning points within the feasible range (2141-54405$), although the Hausman test now does not reject the *RE* model. The *RC* shows no evidence, while the *PMG* estimator provides evidence for a monotonically decreasing evolution instead.

Finally for the NON-OECD countries, we find statistically significant coefficients with the expected sign, for both the homogeneous and intermediate estimators, but the turning points are well beyond the range of observed *GDP* values (80-36884$). This outcome can be interpreted in favor of a monotonically increasing curve. Once again the heterogeneous estimator shows no evidence in favor of the *EKC* curve.

Another relevant outcome emerging from Table 6 regards the role of *epc*. This variable exhibits a positive statistically significant elasticity across estimators, for all samples under investigation. Omitting[3] *epc* from eq. (8) delivers significant coefficients with the expected sign, but turning points appear to be too high, thus unfeasible.[4]

Moving to the third step, we repeat the analysis made so far by estimating the unrestricted model specified in eq. (8) to check for the existence of a *N*-shaped curve instead. The associated results are reported in the following Table 7.

The *FE*, *RE* and *PMG* estimators provide evidence for an inverted *N* curve for the full sample, whose maximum peaks in correspondence of a feasible turning point. The heterogeneous estimator does not provide statistically significant results.

For the group of OECD countries, the *PMG* estimator is the only one giving statistically significant results. The outcome shows a *N*-shaped curve with associated turning points which lie within the observed minimum and maximum *GDP* values.

For the NON-OECD countries, the *FE*, *RE* and *PMG* estimators provide evidence for an inverted *N*-shaped curve whose maximum peaks in correspondence of a feasible turning point, which is however far away from the average *GDP* of the sample (3529$). These results suggest that the group of NON-OECD countries are experiencing a monotonically increasing relationship between

[3] Results are available upon request.
[4] In order to compare our results with Cole (2005), we re-estimate the quadratic functional form without *epc* reducing the sample period to 1984-2000. According to our findings, we can conclude that adding *epc* to the analysis strengthens the evidence in favor to the *EKC* hypothesis when homogeneous estimators are considered. Results are available upon request.

pollution and economic growth, as previously found for the quadratic specification. The heterogeneous estimator does not provide statistically significant results.

Again the *epc* variable exhibits a positive statistically significant elasticity across estimators, for all samples under investigation.

Table 7. The cubic specification of the model

		FE		***RE***		***RC***		***PMG***	
Sample	**Variable**	**Coeff**	**t**	**Coeff**	**t**	**Coeff**	**z**	**Coeff**	**z**
FULL	*gdp*	-2.333***	-5.290	-2.532***	-5.910	-20.013	-0.030	-3.497***	-3.650
	gdp^2	0.474***	8.000	0.502***	8.780	3.444	0.030	0.516***	4.370
	gdp^3	-0.024***	-9.500	-0.025***	-10.330	-0.156	-0.020	-0.023***	-4.850
	epc	0.211***	16.070	0.211***	16.360	0.176**	2.810	0.380***	17.880
	cons	0.236	0.220	0.622	0.600	22.989	0.020		
	Obs	2771		2771		2771		2618	
	Hausman	chi2(4)=23.34							
	TP1	26.74		29.61				176.57	
	TP2	18725.22		19181.48				18271.92	
OECD	*gdp*	4.881	1.250	4.642	1.190	80.178	0.310	100.064***	6.030
	gdp^2	-0.114	-0.270	-0.090	-0.220	-8.113	-0.300	-10.267***	-6.040
	gdp^3	-0.009	-0.610	-0.010	-0.660	0.272	0.280	0.349***	6.010
	epc	0.116**	2.790	0.120**	2.960	0.273*	2.130	0.706***	31.150
	cons	-27.105*	-2.210	-26.345*	-2.150	-262.967	-0.320		
	Obs	792		792		792		748	
	Hausman	chi2(4)=1.86		*Valid*					
	TP1	0.00		0.00				39415.92	
	TP2	19144.16		19142.92				8379.92	
NONOECD	*gdp*	-0.599	-1.000	-0.745	-1.260	-70.871	-0.070	-4.447**	-2.770
	gdp^2	0.220**	2.640	0.242**	2.960	8.275	0.050	0.628**	3.030
	gdp^3	-0.012**	-3.270	-0.013***	-3.610	-0.273	-0.030	-0.027**	-3.080
	epc	0.211***	14.080	0.213***	14.400	0.151*	2.140	0.365***	15.320
	cons	-3.641*	-2.570	-3.366*	-2.410	185.326	0.100		
	Obs	1979		1979		1979		1870	
	Hausman	chi2(4)=16.08							
	TP1	4.78		6.09				235.45	
	TP2	36852.44		35486.90				24008.45	

Notes: the Hausman specification test assumes that the estimates from the random effects models are consistent under the null hypothesis. *Stars denote p-values as follows: * p<0.05; ** p<0.01; *** p<0.001.*

Taking together results in Tables (6) and (7), we can summarize what follows.

For the full sample, the quadratic specification supports the existence of a bell-shaped relationship between carbon dioxide emissions and *GDP*, which is also compatible with the inverted *N* curve found when estimating the cubic functional form.

For the OECD sub-sample, evidence is mixed across estimators and functional forms. The only evidence for a bell-shaped curve is provided by the homogenous estimators for the quadratic specification of the model. On the contrary, evidence of a monotonically decreasing relationship arises when the *PMG* estimators is taken into account. When considering the cubic specification, statistically significant coefficients are obtained only when *PMG* is used. In this case, a *N*-shaped curve describing the CO_2-*GDP* relationship is found. Our results are in line with Martinez-Zarzoso and Bengochea-Morancho (2004) where, by means of the pooled mean group methodology, evidence is found in favor of a *N*-shaped curve to describe the CO_2-*GDP* relationship in 22 OECD countries over the period 1975-1998. Interestingly, compared to their findings, we obtain a higher minimum turning point level (20.557$). This result, given the wider time span of our analysis, suggests that, in this recent period, the *N* curve might have shifted onwards as a consequence of the adoption of new green policies.

For the NON-OECD countries, given the unfeasibility of turning points, both the quadratic and cubic specification of the model suggest that these countries are experiencing a monotonically increasing relationship between pollution and economic growth.

5. Concluding remarks

In this paper we investigated the relationship between CO_2 emissions and per capita *GDP* taking into account some of the main drawbacks that seem to have weaken the existing empirical literature on the so called *EKC* hypothesis. In particular, to correct for possible omitted variable biases, we studied the *EKC* relationship considering electric power consumption as an additional explanatory variable. Furthermore, to control for the sensitivity of empirical results to the chosen econometric model, we compared the performance of alternative panel estimators assuming different degree of heterogeneity within the sample. The analysis involved a large panel of countries over the period 1971-2006 that consists of 77 units including 22 OECD and 55 NON-OECD countries.

Our main conclusions can be summarized as follows.

Firstly, we find that *epc* enters significantly in almost all specifications, meaning that energy consumption is a relevant covariate to explain the relationship between per capita income and CO_2 emissions.

Secondly, our comparison of different alternative panel estimators gives the following insights. In both the quadratic and the cubic functional specification, the *PMG* and the two standard homogenous estimators deliver comparable results for the FULL sample and for the NON-OECD sub-sample. The same is not for the OECD countries. A clue might be found in the higher degree of heterogeneity characterizing this group of nations with respect to the other samples. In this respect, the *PMG* estimator, by accommodating heterogeneity in the short run, has fared very well particularly for the cubic functional form. Conversely, we find that the *RC* model never delivers statistically significant parameters estimate of the models under investigations.

Finally, our findings on the *EKC* relationship seem to go in favor of the inverted U-shaped relationship for the full sample. However, this outcome is not confirmed when moving the analysis at sub-sample level where results highlight a non-homogeneous picture across different groups of nations. It appears, in fact, that, while OECD countries lie on a feasible bell-shaped curve or, according to the estimators, along a monotonic decreasing relationship, the same does not happen for NON-OECD countries. In this latter case, according to our interpretation, the average *GDP* level at which polluting emissions start decreasing is far away from being reached yet. This outcome suggests that our aggregate analysis appears unable to deliver a one-fit-for-all *EKC* relationship useful for policy recommendations. In fact, it seems that, if an *EKC* emerges for the full sample, it is only because the panel analysis pools across two different groups of countries whose observations are mainly dispersed along the opposite arms of the bell. Results on turning points clearly support this last interpretation. In other words, we confirm what found in previous literature that aggregate analysis might be biased when an excessively high degree of heterogeneity characterizes the sample under study. In such a circumstances, only restricting the sample to more homogeneous units can guarantee reliability to the panel approach. Even the distinction between OECD and NON-OECD countries may be not enough since samples built on exogenous criteria do not necessarily guarantee the requested degree of homogeneity. Conversely, it might be more appropriate to combine the panel approach with a country by country investigation intended to develop an endogenous criteria for panel aggregation. This analysis goes beyond our scope and is left for further research.

References

Aslanidis, N. (2009). “Environmental Kuznets Curves for Carbon Emissions: A Critical Survey”. *FEEM Working Paper*, **75**.

Apergis, N. and Payne, J. (2009). “CO2 emissions, energy usage and output in Central America”. *Energy Policy*, **37**, 3282-3286.

Azomahou, T., Laisney, F. and Van, P. N. (2006). “Economic development and CO2 emissions: A nonparametric panel approach”. *Journal of Public Economics*, **90**, 1347-1363.

Baltagi, B. H., Bresson, G. and Pirotte, A. (2004). “Tobin q: forecast performance for hierarchical Bayes, shrinkage, heterogeneous and homogeneous panel data estimators”. *Empirical Economics*, **29**, 107-113.

Baltagi, B. H., Griffin, J. M. and Xiong, W. (2002). “Comparison of forecast performance for homogeneous, heterogeneous and shrinkage estimators: Some empirical evidence from US electricity and natural-gas consumption”. *Economic Letters*, **76**, 375-382.

Baltagi, B. H., Griffin, J. M. and Xiong, W. (2000). “To pool or not to pool: Homogeneous versus heterogeneous estimators applied to cigarette demand”. *Review of Economics and Statistics*, **82**, 117-126.

Beltratti, A. (1997). “Sustainable Use of Renewable Resources”. In Chichilnisky, G., Heal, G. and Vercelli, A. (eds), *Environmental Economics: Growth and Uncertainty*, Kluwer Academic Publisher.

Cole, M. A. (2005). “Re-Examining the Pollution-Income Relationship: A Random Coefficient Approach”. *Economics Bulletin*, **14**, 1-7.

Copeland, B. R. and Taylor, M. S. (2004). “Trade, growth and the environment”. *Journal of Economic Literature*, **42**, 7-71.

de Bruyn, S. M., van den Bergh, J. C. J. M. and Opschoor, J. B. (1998). “Economic growth and emissions: Reconsidering the empirical basis of environmental Kuznets curves”. *Ecological Economics*, **25**, 161-175.

Dinda, S. (2004). “Environmental Kuznets Curve Hypothesis: A Survey”. *Ecological Economics*, **49**, 431-455.

Dinda, S., Coondoo, D. and Pal, M. (2000). “Air quality and economic growth: an empirical study”. *Ecological Economics*, **34**(3), 409-423.

Ferda, H. (2009). “An econometric study of CO2 emissions, energy consumption, income and foreign trade in Turkey”. *Energy Policy*, **37**(3), 1156-1164.

Figueroa E. B. and Pastén, R. C. (2009). “Country-specific Environmental Kuznets Curves: a Random Coefficient approach applied to high-income countries”. *Estudios de Economia*, **36**(1), 5-32.

Galeotti, M., Manera, M. and Lanza, A. (2009). "On the Robustness of Robustness Checks of the Environmental Kuznets Curve Hypothesis". *Environmental & Resource Economics*, **42**(4), 551-574.

Grossman, G. M. and Krueger, A. B. (1995). "Economic growth and the environment". *Quarterly Journal of Economics*, **110**, 352-377.

Hausman, J. A. (1978). Specification Tests in Econometrics. *Econometrica*, 46, 1251-1271.

Holtz-Eakin, D., and Selden, T. M. (1995). "Stoking the fires? CO2 emissions and economic growth". *Journal of Public Economics*, **57**, 85-101.

Hsiao, C., M.H. Pesaran and A.K. Tahmiscioglu, Bayes estimation of short-run coefficients in dynamic panel data models. In: C. Hsiao, K. Lahiri, L.-F. Lee and M.H. Pesaran, Editors, *Analysis of Panels and Limited Dependent Variable Models*, Cambridge University Press, Cambridge (1999), pp. 268–296.

Im, K. S., Pesaran, M. H., and Shin Y. (2003). "Testing for Unit Roots in Heterogeneous Panels". Journal of Econometrics, Vol. 115, p. 53-74.

Koop, G. and Tole, L. (1999). "Is There an Environmental Kuznets Curve for Deforestation?". *Journal of Development Economics*, **58**, 231-244.

Lean, H. H. and Smyth, R. (2010). "CO2 emissions, electricity consumption and output in ASEAN". *Applied Energy*, **87**, 1858-1864.

List, J.A. and Gallet, C.A. (1999). "The environmental Kuznets curve: does one size fit all?". *Ecological Economics*, 31, 409-423.

Maddala, G.S. and Wu, S. (1999). "A Comparative Study of Unit Root Tests With Panel Data and A New Simple Test". *Oxford Bulletin of Economics and Statistics*, 61, 631-652.

Martinez-Zarzoso, I and Bengonchea-Morancho A. (2004). "Pooled mean group estimation of an environmental Kuznets curve for CO_2". *Economics Letters*, **82**, 121-126.

Mazzanti, M. and Musolesi, A. (2009). "Carbon Kuznets Curves: Long-Run Structural Dynamics and Policy Events". *FEEM Working Paper*, **87**.

Pedroni, P.L. (2004). "Panel Cointegration; Asymptotic and Finite Sample Properties of Pooled Time Series Tests with an Application to the Purchasing Power Parity Hypothesis", *Econometric Theory*, **20**(3), 597-625.

Pesaran, M. H., Shin, Y. and Smith, R. (1999). "Pooled mean group estimation of dynamics heterogeneous panels". *Journal of the American Statistical Association*, **94**, 621-634.

Pesaran, M. Hashem and Smith, R. (1995). "Estimating Long-Run Relationships from Dynamic Heterogenous Panels". *Journal of Econometrics*, **LXVIII**, 79-113.

Richmond, A.K., and Kaufmann, R.K. (2006). "Is there a turning point in the relationship between income and energy use and/or carbon emissions?". *Ecological Economics*, **56**, 176-189.

Selden, T. M. and Song, D. (1994). “Environmental quality and development: is there a Kuznets curve for air pollution?”. *Journal of Environmental Economics and Environmental Management*, **27**, 147-162.

Shafik, N. (1994). “Economic development and environmental quality: an econometric analysis”. *Oxford Economic Papers*, **46**, 757-773.

Stern, D. I. (2004). “The Rise and Fall of the Environmental Kuznets Curve”. *World Development*, **32**(8), 1419-1439.

Stern, D. I. and Common, M. S. (2001). “Is there an environmental Kuznets curve for sulfur?”. *Journal of Environmental Economics and Management*, **41**, 162-178.

Swamy, P. and Mehta, J. S. (1975). “Bayesian and Non-Bayesian Analysis of Switching Regressions and of Random Coefficient Regression Models”. *Journal of the American Statistical Association*, **70**, 593-602.

Westerlund , J. (2007). “ Testing for Error Correction in Panel Data”. *Oxford Bulletin of Economics and Statistics*, **69**, 709-748.

World Bank. *World development indicators*. Washington (DC): World Bank; 2009.