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CO_2 Kuznets Curve Revisited: From Cross-Sections to Panel Data Models

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ABSTRACT: The Environmental Kuznets Curve (EKC) predicts that environmental degradation intensifies when per capita income increases and subsequently subsides after a certain income level is reached, resulting in an inverted U-shaped relationship. There is abundant literature on the topic that corroborates the existence of a positive income elasticity for environmental quality. However, results are controversial.
We take the case of CO_2, by comparing the results of the cross-sectional estimates with those derived from a panel approach. To this end, we use data from 182 countries during the period 1992-2011. We found that the EKC hypothesis is acceptable under both approaches, although the estimated turning points in cross-sections seem unreliable. Our application underlines the importance of adequately address central problems such as heterogeneity, structural breaks and spatial interaction.

JEL Classification: Q25; L83.

Keywords: Kuznets environmental curve; CO_2 emissions; spatial effects; structural breaks; heterogeneity.

Una revisión de la curva de Kuznets para el CO_2: de los modelos de corte transversal a los de datos panel

RESUMEN: La curva de Kuznets (EKC) predice que la degradación medioambiental se intensifica inicialmente al aumentar la renta per cápita, para disminuir a continuación tras haber alcanzado cierto nivel de renta o *turning point*. Esta estructura se traduce en una relación en forma de U invertida entre ambas variables.

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Existe abundante literatura sobre el tema que corrobora la existencia de una elasticidad neta positiva para la calidad medioambiental. Sin embargo, los resultados son controvertidos.
Analizamos el caso de CO_2 comparando los resultados de las estimaciones transversales, con las derivadas de un enfoque panel. Para ello utilizamos datos de 182 países durante el periodo 1992-2011. Comprobamos que la hipótesis EKC resulta aceptable bajo ambos enfoques, aunque los *turning point* estimados en los cortes transversales son poco creíbles. Nuestra aplicación subraya la importancia de tratar adecuadamente problemas centrales como la heterogeneidad, las rupturas estructurales y la interacción espacial.

Clasificación JEL: Q25; L83

Palabras clave: curva medioambiental de Kuznets; emisiones de CO_2; efectos espaciales; cambios estructurales; heterogeneidad.

1. Introduction

It is widely acknowledged that pollution induced by human activities is a major threat to sustainable development. The Fifth Assessment Report from the Intergovernmental Panel on Climate Change (IPCC, 2013-Working Group I; IPCC, 2014) declares that «it is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century». Carbon dioxide (CO_2) is the most important pollutant of the greenhouse gases emitted by human activities, though not the only one. United Nations Framework Convention on Climate Change distinguishes between *direct greenhouse gases*, such as carbon dioxide (CO_2), and *indirect greenhouse gases*, which also contribute to global warming such as Sulphur dioxide (SO_2), and advises that the situation of all these gases be monitored.

It is important to distinguish their impact, local or global, as made clear in the influential seminal papers of Grossman and Krueger (1991, 1995), Shafik and Bandyopadhay (1992), Panayotou (1993, 1997), Selden and Song (1994) and Galeotti, (2007). Local pollutants, such as Sulphur oxides, nitrogen oxides, lead or carbon monoxide have local health impacts by affecting water or local air conditions. The damage of global pollutants, CO_2 in particular, is less immediate since, being locally innocuous, they impact the global environment over the long term.

Part of the literature on environmental economics has focused on the relationship between environmental degradation and economic growth using different indicators, countries (regions, cities, etc.), time periods and technical approaches. Consequently, researchers have derived different and sometimes conflicting results. Excellent reviews can be found in Panayotou (2000), Dasgupta e*t al.* (2002), Lieb (2003), Dinda (2004), Kaika and Zervas (2013a, 2013b) or, more recently, Stern (2015).

A common thread in this literature has been the so-called Environmental Kuznets Curve (EKC), which predicts an inverted-U shaped relation between environmental degradation and economic growth in an obvious analogy with the income-inequality relationship postulated by Kuznets (1955). In the same vein, Panayotou (1993) and Arrow e*t al.* (1995) talk about the transition from primitives agrarian economies to polluting industrial economies, and finally, to clean service economies.

There is a solid theoretical background giving support to the inverted U-shaped pattern relying on structural and behavioural factors. The structural approach includes elements related to the scale of economic activity, sectoral composition of the output or technological progress (Grossman and Krueger, 1995; Panayotou, 1993; Kaufman e*t al.*, 1998). Behavioural factors focus on the income elasticity of the demand for environmental quality, so that the willingness to pay for higher environmental quality increases with income (McConnell, 1997; Islam e*t al.*, 1999; Lekakis and Kousis, 2001; Roca, 2003). Other (secondary) factors used to support this relation are the relocation of industrial activities, the patterns of international trade, demography, or the income distribution among families (Magnani, 2000; Heenrink e*t al.*, 2001; Heil and Selden, 2001; Shi, 2003).

The downward segment of the curve has received much skepticism. Leading authors such as Arrow *et al*. (1995), Panayotou (1997), Magnani (2001) or Lieb (2003) sustain that it is a mere statistical result with no causal interpretation. It is very naïve to expect environmental problems be solved merely by economic growth. Conversely, the role of public and private institutions remains crucial, as stressed, among others, by Baldwin (1995), de Bruyn (1997), Runar e*t al.* (2016) or Apergis and Ozturk (2015).

A different issue is the drivers behind the emissions. Kaika and Zervas (2013a, 2013b) indicate that they are not limited to economic growth; international trade, technology, energy mix, etc. can also have an impact on the EKC. However, results related to these drivers are conflicting and tend to obscure the essence of the discussion: what is the relation between demand for environmental quality and economic growth?

Notable authors such as Stern (1998), Agras and Chapman (1999) or Neumayer (2002) conclude that income is the most important variable for explaining CO_2 emissions. Azomahou e*t al.* (2006) is a good example, when they advocate for an EKC equation without explanatory variables, other than per capita GDP. In their words, if we are interested in the shape of the relationship with GDP then «determinants of CO_2 emissions which are not correlated with GDP become irrelevant. Moreover, the impact of determinants which are correlated with GDP will be captured in the effect of GDP». This can be a drawback «if we purport to determine the *ceteris paribus* impact of GDP on CO_2 emissions —but what list of regressors would guarantee this?»; it may also be an advantage «if we are interested in the global effect of GDP, including indirect effects linked with omitted variables». Other authors, such as Holtz-Eakin and Selden (1995), List and Gallet (1999) or Yang e*t al.* (2015) recommend maintain the EKC equation as simple as possible; this is also our approach.

The EKC hypothesis has been confirmed for several *local* pollutants such as Sulphur oxides, nitrogen oxides, etc., in an impressive applied literature (see Panayotou, 2000; Stern and Common, 2001; Galeotti, 2007; Stern, 2015). However, the empirical evidence is not conclusive regarding *global* pollutants such as CO_2.

Another point of debate refers to the type of data. At the beginning, the lack of information for many environmental indicators lead researchers to formulate simple cross sections or short panels. However, nowadays the situation has changed quite a lot because of greater accessibility to data, which has given rise to numerous studies based on pure time series analysis. Table 1 collects a small sample of papers built on this approach in the last decade.

Table 1. Studies on CO_2 emissions using time series data

Author(s)	*Geographical area*	*Period*	*Main conclusion*
Kunnas and Myllyntaus (2007)	Finland	1800-2003	Inc. monotonically
Soytas *et al.* (2007)	United States	1960-2004	Inc. monotonically
Akbostanci *et al.* (2009)	Turkey	1968-2003	Inc. monotonically
He & Richard (2010)	Canada	1948-2004	Inc. monotonically
Iwata *et al.* (2010)	France	1900-2003	Inverted U-shape
Iwata *et al.* (2012)	11 OECD countries	1967-2003	Inc. monotonically
Jayanthakumaran *et al.* (2012)	China/India	1971-2007	Inverted U-shape
Kholer (2013)	South Africa	1960-2009	Inverted U-shape
Alam (2014)	Bangladesh	1972-2010	Inc. monotonically
Lau *et al.* (2014)	Malaysia	1970-2008	Inverted U-shape
Yavuz (2014)	Turkey	1960-2007	Inverted U-shape
Al-Mulali (2015)	Vietnam	1981-2011	Inc. monotonically
Balaguer and Cantavella (2016)	Spain	1874-2011	Inverted U-shape
Dogan and Turkekul (2016)	USA	1960-2010	Inc. monotonically

Large part of this literature finds no traces of a turning point. Of course, this is not a sufficient condition to negate EKC because it may be due to a particular feature of the case under study or, simply, the turning point occurs well outside the range of income levels (Panayotou, 2000). Despite the appealing of the time series approach, most studies on CO_2 are based on panel data. Combining data from different countries improves the information and permits a richer econometric specification. In addition, it is difficult to extract general conclusions about the EKC by using data on a single nation. Both are good reasons supporting the use of panel data models, a sample of those published in the last decades appear in Table 2.

Table 2. Studies on CO_2 emissions using panel data models

Author(s)	*Geographical area*	*Period*	*Main conclusion*
Shafic & Bandyopadhyay (1992)	149 countries	1960-1990	Inverted U-shape
Holz-Eakin & Selden (1995)	130 countries	1951-1986	Inverted U-shape
Cole *et al.* (1997)	7 World regions	1960-1991	Inverted U-shape
Moomaw and Unruh (1997)	16 OECD countries	1950-1992	Inverted U-shape
Schmalensee *et al.* (1998)	47 countries	1950-1990	Inverted U-shape
Agras and Chapman (1999)	34 countries	1971-1989	Inverted U-shape
Galleoti and Lanza (1999)	110 countries	1971-1996	Inverted U-shape
Auffhammer *et al.* (2000)	30 Chinese provinces	1985-1995	Inverted U-shape
Halkos and Tsionasb (2001)	61 countries	1980-1991	Inc. monotonically
Neumayer (2002)	148 countries	1960-1988	Inverted U-shape
Pauli (2003)	29 OECD countries	1970-1988	Inverted U-shape
Dijkgraaf and Vollebergh (2005)	24 OECD countries	1960-1997	Inverted U-shape
Azomahou *et al.* (2006)	100 countries	1960-1996	Inc. monotonically
Galleoti *et al.* (2006)	28 OECD; 93 non OECD countries	1960-1997 1971-1997	Inverted U-shape
Richmond & Kaufman (2006)	36 countries	1973-1997	Inc. monotonically
Akbostanci *et al.* (2009)	58 Turkish provinces	1992-2001	Inc. monotonically
Aslanidis and Iranzo (2009)	77 non OECD countries	1971-1997	Inc. monotonically
Wang *et al.* (2011)	28 Chinese provinces	1995-2007	Inverted U-shape
Anjum *et al.* (2014)	143 countries	1950-2011	Inverted U-shape
Yang *et al.* (2015)	67 countries	1971-2010	Inverted U-shape

It is difficult to extract general guidelines from Table 2 because this is a very heterogeneous collection of papers, with large and very short panels, different spatial layers, treated parametrically or non-parametrically, etc. However, compared with the pure time series case, panel data models tend to favor the EKC hypothesis.

Table 3 summaries some of the main studies that examine the EKC hypothesis using simple cross sectional data. As can be seen, these studies were conducted mostly in the early stages of EKC debate and implicitly assume that all countries in the sample are homogeneous.

Table 3. Studies on CO_2 emissions using simple cross section data

Author(s)	*Geographical area*	*Period*	*Main conclusion*
Shafik and Bandyopadhay (1992)	135 countries	1985	Inc. monotonically
Holtz-Eakin and Selden (1995)	108 countries	1986	Inc. monotonically
Tucker (1995)	137 countries	1971-1991	Inverted U-shape
Carson *et al.* (1997)	50 US States	1990	Inverted U-shape
Robert and Grimes (1997)	148 countries	1962-1991*	Inverted U-shape
Magnani (2001)	156 countries	1970; 1980; 1990	Inverted U-shape
Hill and Magnani (2002)	156 countries	1970; 1980; 1990	Inverted U-shape
Robert and Grimes (2003)	154 countries	1989; 1998	Inverted U-shape
Chow and Li (2014)	132 countries	1992-2004*	Inverted U-shape

* A regression for each year was estimated separately.

To complete the picture, let us mention that, in the last two decades, the literature on CO_2 has become more sensitive to the spatial layout. Given that emissions in one region might have consequences on neighbouring regions, it is important to account for the existence of spillovers as shown by Rupasingha *et al.* (2004), in the case of toxic pollutants, Maddison (2006, 2007) for four local pollutants and Poon et al. (2006) for Sulphur dioxide and soot emissions. All of them conclude that the EKC equation should control for spillovers effects. A non-exhaustive collection of papers in this vein appears in Table 4.

Table 4. Studies on CO_2 emissions controlling for spatial effects in panel models

Author(s)	*Geographical area*	*Period*	*Main conclusion*
Auffhammer and Carson (2008)	30 Chinese provincial entities	1985-2004	Inverted U-shape
Burnett *et al.* (2013)	48 US states	1970-2009	Inverted U-shape
Hosseini and Kaneko (2013)	129 countries	1980-2007	Inverted U-shape
Danaeifar (2014)	30 European countries	1992-2008	Inverted U-shape
Zhao *et al.* (2014)	30 Chinese provinces	1991-2010	Dec. monotonically
Zheng *et al.* (2014)	30 Chinese provincial entities	1998-2010	Inverted N-shape
Georgiev and Mihaylov (2015)	30 OECD countries	1990-2005	Inc. monotonically
Kang *et al.* (2016)	30 Chinese provinces	1997-2012	Inverted N-shape

Overall, the explicit inclusion of cross-sectional mechanisms in the equation tends (i) to reinforce the EKC hypothesis and (ii) to move upwards the location of the turning point in relation to the case of pure non spatial models.

The use of cross sectional and panel data models for testing the EKC hypothesis has been strongly criticized arguing that only time series analysis for single countries can shed light on this hypothesis (Roberts and Grimes, 1997; Vincent, 1997; Carson e*t al.,* 1997; Unruh and Moomaw, 1998; Borghesi, 1999; List and Gallet, 1999; Egli, 2001; Pauli, 2003; Lindmark, 2004; Dijkgraaf and Vollebergh, 2001, 2005; Jaunky, 2011). A major argument is that the EKCs estimated by cross sectional or pooled data are just a juxtaposition of an increasing relationship (ascendant segment) for one group of countries with a decreasing one (descendant segment) for another group of countries so that the final result, a kind of inverted U, is artificial. For example, Dijkgraaf and Vollebergh (2005) compare the results obtained from panel and time series data for CO_2 emissions in OECD countries for the period 1960-1997. They found conflicting results: an inverted EKC emerges from the panel data estimates whereas the time series approach confirms the EKC only for five countries in the sample. The conclusion of Dijkgraaf and Vollebergh is that there is no a common EKC for all countries in the sample. List and Gallet (1999) also stress the importance of controlling for all types of heterogeneity.

Moreover, the use of a large collection of countries in the study, with the aim of better capture different phases of the EKC, does not ensure that the results will be consistent. Holtz-Eakin and Selden (1995), for example, find evidence for the EKC hypothesis for CO2 emissions with a panel data approach but reject the EKC with simple cross sectional estimates. In the same line, Hill and Magnani (2002) highlight the great instability of the estimated turning points in cross-sectional equations (they use the term volatility), which may be due to many different misspecifications.

Our paper aims to be a reflection of the EKC debate. We have not any priori about the shape of the curve. Our concern focuses on the «*ductility*» of the techniques and of the data. As indicated, we use a very simple reduced form where no explanatory variables other than income are included. On this premise, we contribute to the EKC literature with a careful treatment of the spatial aspects of the equation. We find interesting the work of Wagner (2008), who points out to the use of weak estimation techniques as one plausible cause of the discrepancies in the EKC literature: «the seemingly strong evidence for an inverted U-shaped relationship between these variables (income/pollutants) obtained with commonly used methods is entirely spurious and vanishes when resorting to estimation strategies that take the discussed problems into account».

The structure of the paper is as follows. In the next Section, we describe our database and statistical sources. The third Section is devoted to the panel data case. Next, Section 4 focuses on the cross-sectional approach. Finally, the paper concludes with a summary of main conclusions.

2. Data

Our data consists of per capita CO_2 emissions (pcco2) and per capita GDP (pcgdp) for a panel of 182 countries over the period 1992-2011. The data proceeds, respectively, from the United States Energy Information Administration (EIA) and the United Nations (UN).

Table 5 summarizes main facts for four groups of countries defined according to the Human Development Index (HDI) developed by the United Nations[1]. The outstanding feature of the data is their heterogeneity. The discrepancy between the maximum and the minimum is, approximately, 25 to 1 in the case of income and 15 to 1 in the case of CO_2 emissions.

Table 5. pcco2 and pcgdp by HD groups and decades

		WORLD	HDI I	HDI II	HDI III	HDI IV
1992	**pcco2**	3.9	11.8	8.6	1.6	0.8
	pcgdp	6276.2	21189.4	6728.3	1376.9	800.2
2001	**pcco2**	3.9	13.9	8.6	1.6	0.7
	pcgdp	6953.6	26490.5	6749.8	1695.4	839.1
2011	**pcco2**	4.6	15.7	8.7	2.1	0.7
	pcgdp	8424.0	29440.1	6759.5	2449.1	1100.3

pcco2*:* Per capita carbon dioxide emissions from the consumption of energy (metric tons of carbon dioxide per person). *Source:* EIA. **pcgdp:** Per capita Gross Domestic Product in 2005 US$.
Human development groups: **HDI I**: Very High Human Development; **HDI II**: High Human Development; **HDI III**: Medium Development; **HDI IV**: Low Human Development. *Source:* UN.

Table 6 shows that the emissions of the pollutant have increased in the two decades. However, this increment is far from being uniform.

Table 6. Percentage of variation of pcco2 and pcgdp by HD groups and decades

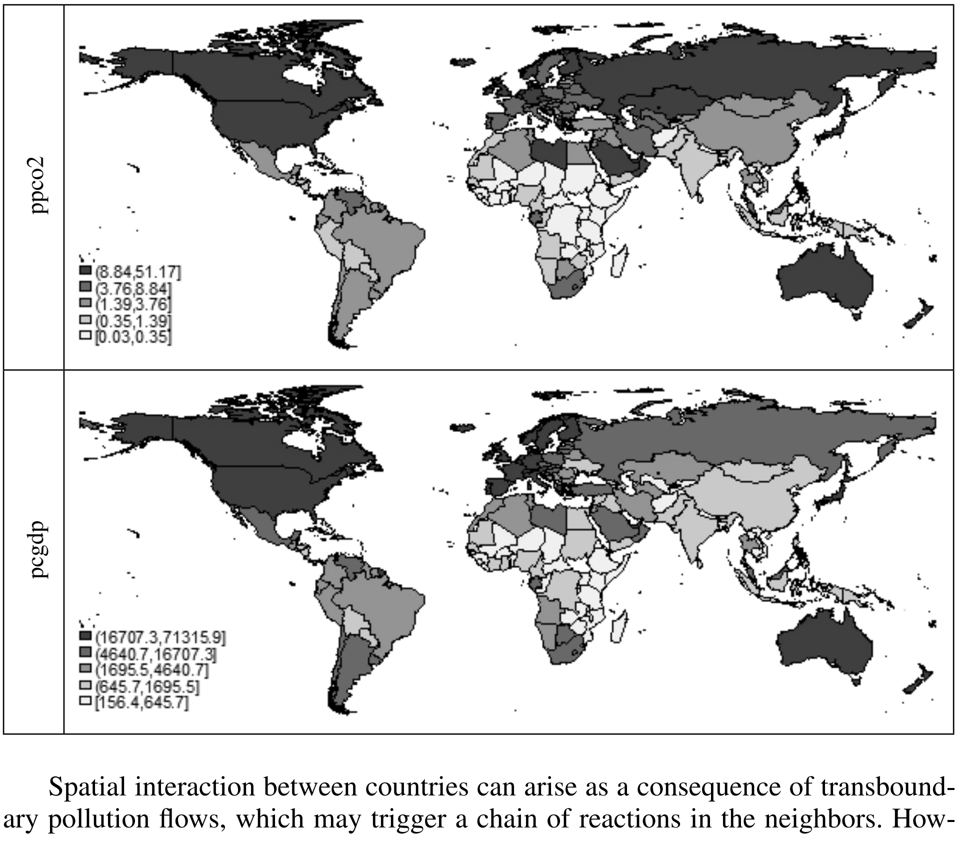
	pcco2			*pcgdp*		
	2001/1992	*2011/2001*	*2011/1992*	*2001/1992*	*2011/2001*	*2011/1992*
WORLD	–0.3	18.4	18.0	10.8	21.1	34.2
HDI I	17.3	13.3	32.9	25.0	11.1	38.9
HDI II	0.5	0.7	1.2	0.3	0.1	0.5
HDI III	1.0	25.5	26.8	23.1	44.5	77.9
HDI IV	–13.4	3.7	–10.2	4.9	31.1	37.5

[1] HDI is a commonly used measure of the well-being of a country. It takes into account, in addition to economic growth (GDP per capita), health and education. We used the HDI index to group the nations since it is comparatively more comprehensive than GDP per capita in the sense that it includes aspects that may transform the economic growth into human development; also, this index offers a better representation reflecting inequalities in the distribution of income in a country.

The acceleration in the first decade of the new century coincides with the momentum in the Chinese and Indian economies, which boosted CO_2 emissions especially in group III. Group IV includes the poorest nations in the World and has the lowest increments in per capita emissions, the contrary of Group I made up of highly developed nations. Surprisingly, the relation between emissions and gdp per capita is higher in the group of poor countries (with a linear correlation of 0.65 for the whole period), whereas in groups I and II this coefficient is 0.43 and 0.38, respectively.

Figure 1 adds another piece of information which is the spatial distribution of the data for the average of the period. There are clusters of nations with the same colour in both maps, meaning that geographical location and indicator (income, emissions) are not independent events. This is spatial autocorrelation: the spatial layout of the indicator is not random. Moreover, the two maps display similarities, which highlight the connections between both variables. This is spatial cross-correlation among emissions and income. In fact, it is not a surprise to find this kind of regularities: as discussed in previous section, Space matters also for CO_2 emissions.

Figure 1. Spatial distribution of ppco2 and pcgdp.
Average of the period 1992-2011



Spatial interaction between countries can arise as a consequence of transboundary pollution flows, which may trigger a chain of reactions in the neighbors. However, this mechanism is more likely to work at a finer geographical scale than ours and with pollutants with a stronger short-run impact than CO_2.

Part of the literature on EKC highlights the importance of strategic interactions among governments. An argument often used is that national political leaders are reluctant to promote measures to control the level of emissions in their own country if neighboring countries remain passive, and vice versa. Similarly, environmental standards have also been used as an incentive to attract capital or improve trade connections which means that changes in environmental policies, in a certain country, frequently result from similar changes in neighboring countries, with the purpose of preserving competiveness.

There are other factors which may produce spatial regularities such as the 'pollution displacement' hypothesis, according to which high-income countries export their pollution by relocating of the most contaminant parts of the chain of production, to lower-income countries. Given that there is a strong spatial clustering of high and low income countries in the World, this results in a similar grouping in terms of environmental degradation (or exporters and importers of environmental degradation).

From another perspective, we should recall that one of the most important factors allowing for reductions in emissions is technological change. However, technology is not evenly distributed. To the contrary, technical improvements are spread according to a very hierarchical process from innovators, developers, to imitators and final users. This is also true from a spatial perspective where is widely recognized that geography is a major determinant of technology diffusion. Therefore, we should find traces of spatial structure in per capita emissions due to the diffusion of technological advances. A similar reasoning can be made in relation to social capital, as a key factor fueling economic growth. Social capital is a rather vague notion, mixture of social and institutional trust, common rules, compliance to social norms, networking, civic participation, etc. Whatever definition we may prefer, social capital is not uniformly distributed but clustered according a high-low income scheme. More important for us, social capital has been found to have a strong effect to shape individual and collective action in order to achieve a stronger environmental awareness (Pretty and Smith, 2003). It is also an essential element for framing public and private institutions with the aim of strengthen the position in favor of economic models more respectful of the environment. This point connects the discussion with the initial notion of strategic interaction among countries.

In practice, it may prove difficult to pin down the reasons for spatial relationships in the data, because there might be different factors working at the same time. However, it is very important to be aware of its presence if we want to know how the EKC works. For example, spatial dependence means that the reaction of a country is conditional to its neighbors, which must be taken into account to fully understand the chain of reactions. Moreover, it is a well-known result in the literature on spatial data that the wrongly omission of spatial dynamics in the equation leads to biased estimates and weak inference (i.e., the symptoms of structural instability, often found in EKC studies, may arise because of the omission or a careless treatment of the spatial effects).

Consequently, the next point is to check for the existence of spatial regularities in our EKC data. There is a huge literature (Lesage and Pace, 2009) on this topic from which we select the simple Moran's I test. Previously, we need to define the so-called weighting matrix, denoted as **W**, whose purpose is to inform how the space is structured. This is a square matrix of order N (number of individuals in the sample) with zeros in the diagonal; the terms outside the diagonal indicate which individuals interact (i.e., a 1 in the *(i, j)* cell indicates that j interacts with *i*, and 0 otherwise); see Harris e*t al.* (2011) for other alternatives to build **W**.

In our case, we have chosen a classical five nearest-neighbours pattern, where a 1 in *(i, j)* cell indicates that country j is one of the 5 nearest neighbours of *i*; 0 otherwise. This pattern is a reasonable approximation to the spatial layout shown in Figure 1 and assures an adequate balance between connected and non-connected cells. Results in Table 7 show that there is a strong spatial dependence in the distribution of CO_2 and per capita income. The spatial layout is also a relevant aspect for the bivariate case, which frames the relation between the two variables.

Table 7. Moran's I coefficients of spatial cross correlation. Univariate and bivariate

	ppco2	*pcgdp*	*(ppco2, pcgdp)*
1992	0.52***	0.56***	0.38***
2001	0.50***	0.56***	0.39***
2011	0.44***	0.56***	0.32***

*** *p* value lower than 0.01.

3. Empirical results: the panel data case.

Let us begin with the panel version of the EKC, whose basic specification reads as:

$$y_{it} = \beta_{0i} + \beta_1 x_{it} + \beta_2 x_{it}^2 + \varepsilon_{it};\ \ i = 1, 2, ..., N \quad t = 1992, ..., 2011 \tag{1}$$

y_{it} is the log of CO_2 per capita emissions of country i in period *t*, x_{it} is the log of per capita gdp, and ε_{it} a white noise error term. As claimed by Stern (2004), we should check for the statistical properties of the series to confirm the statistical validity of the equation, before proceeding with estimation. Main results appear in Appendix A, which indicate that the two panel series are I (1) but cointegrated. The relation is not spurious.

However, the EKC of (1) is affected by a problem of structural break. The test of Bai and Perron (1989), obtained individually for each country, confirms that in 72 cases there exists at least one structural break. The date of the break is not homogeneous among the countries, although the Mode is 2003. Bai (2010) developed a simple procedure to consistently estimate a common break, in mean and variance, for a panel data set by using LS estimates. The conclusion of Bai's procedure clearly points to 2004[2]. Accordingly, the sample has been divided in two subsamples: 1992-2003 and 2004-2011.

Table 8 shows the panel estimates of the EKC equation in both periods. The F test of individual unobserved effects confirms the heterogeneity among the 182 countries, in the two equations. Moreover, these unobserved effects are highly correlated with the endogenous variable as indicated by the Hausman test, therefore we should use fixed effects. We have not found traces of temporal unobserved effects, so no action was taken in this aspect. Overall, we confirm the EKC hypothesis in both periods, although there are equations in Table 8 challenging its validity.

Additionally to the heterogeneity problem, there remains a strong cross-sectional dependence in the residuals, as shown by the CD test of Pesaran (2009); so we need an equation with unobserved fixed effects and spatial interaction mechanisms. The differences arise in the last point. The LRs that appear at the bottom of the Table allow to set up a model selection exercise according to a Gets approach (Mur and Angulo, 2009). The decision in the second period is clear in favour of a SARAR structure. However, the evidence in the first period points to a SEM mechanism.

The interaction is rather weak in the first period, only through the error terms. However, in the second period it extends to both the means equation and the error terms. This implies that shocks produced locally in the region affect to all the countries located in the same region (residual dependence), but also that countries in the same region are interacting explicitly among them (mean equation dependence), emphasizing the importance of strategic interaction[3].

Other differences are also remarkable. The Turning point estimated in the first period is relatively high, \$101,496, obtained from the SEM equation (with a bootstrapped 5% confident interval of \$98,654-\$104,338), whereas that of the second period, obtained from the SARAR equation, is \$47,943 (with a bootstrapped 5% confident interval of \$46,697-\$49,189). Let us note that the first turning point is twice the second but we do not have a clear cut explanation for this result which is probably connected with the low estimate for β_2 in the first subperiod (the curve is almost a straight line). In some sense (high turning point, smooth descendent phase of the curve), we can say that the EKC was less effective in the nineties[4].

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[2] The year 2004 is very significant for us because the Kyoto Protocol was adopted in December 1997 but entered into force only in February 2005. Moreover, 2004 is the year that marks the end of the period of turbulences of the last nineties (dotcom bubbles, «tequila» crisis, Asian financial crisis, etc.) and the beginning of a period of sustained economic growth until de crash of 2007. The last crash has not been detected as a breakpoint in our dataset, possibly, because of the trimming of the sample as recommended for the Bai and Perron (1989) procedure.

[3] Applied literature on spatial econometrics (i.e., Fingleton *et al.,* 2012, Martin, 2012) confirms that spatial interaction weakens in periods of turmoil and crisis but increases in periods of recovery.

[4] As kindly suggested by one of the referees, this result may be due to increasing investment in renewable energy in order to meet climate change goals as well as because the costs for renewable energy are falling worldwide in recent years. Another explication to the shift in the turning point is the increasing transfer of environment-friendly technologies, at a reasonable cost, from developed countries to emerging, poorer countries.

Table 8. Panel data model estimates

		First period: 1992-2003 182 counties, 12 cross-sections = 2184 observations						*Second period: 2004-2011 182 counties, 8 cross-sections = 1456 observations*					
		POOL	*FE*	*FE SARAR*	*FE SDM*	*FE SLM*	*FE SEM*	*POOL*	*FE*	*FE SARAR*	*FE SDM*	*FE SLM*	*FE SEM*
β_1		2.483***	0.172	0.424	-0.017	0.161	0.830**	2.872***	1.340***	0.776***	1.357	1.383***	1.324***
β_2		–0.091***	0.021**	–0.018*	0.029	–0.015*	–0.036**	–0.118***	–0.062***	–0.036**	–0.064	–0.064**	–0.061***
ρ				0.263*	0.318***	0.818***				0.575***	0.062*	–0.098**	
λ				0.374**			0.638***			–0.860***			–0.103**
σ^2		0.7338	0.174	0.028	0.025	0.025	0.025	0.630	0.214	0.037	0.040	0.040	0.040
Log-likelihood		–2759.57	811.91	884.03	889.775	881.92	883.69	–1728.62	272.97	290.45	275.886	275.55	275.66
H_0: No unobserved effects (F test)			279.86 (0.000)						102.84 (0.000)				
H_0: Random effects (Hausman test)			92.74 (0.000)						79.55 (0.000)				
H_0: No spatial correlation (CD Pesaran test)			7.24 (0.000)						8.34 (0.000)				
LR Tests	H_0: SLM H_A: SARAR					4.21 (0.039)						29.81 (0.000)	
	H_0: SEM H_A: SARAR						0.67 (0.414)						29.59 (0.000)
	H_0: SLM H_A: SDM					15.71 (0.000)						0.05 (0.827	
	H_0: SEM H_A: SDM						2.83 (0.093)						0.16 (0.692)

*** *p* value lower than 1%.; ** *p* value lower than 5%; * *p* value lower than 10%.
All equations, but the POOL model, include individual effects. The estimates of the spatial lags of the exogenous variable in the SDM equation are omitted.
ρ is the coefficient of the spatial lag of the endogenous variable in the equation for the mean.
λ is the coefficient of spatial autocorrelation of the errors.

Results on Direct, Indirect, and Total elasticities corresponding to the SARAR equation appear in Table 9 and Figure 2. The elasticities are evaluated using the mean values of the variables in the period 2004-2011, and the corresponding estimates of the parameters of the SARAR equation in Table 8 (see Lesage and Pace, 2009, for the details).

Table 9. Summary of elasticities. SARAR panel model. 2004-2011

	Mean	*Standard Dev*	*Minimum*	*Maximum*
Total elasticities	0.381**	0.215	–0.072	0.775
Direct elasticities	0.172**	0.126	–0.074	0.420
Indirect elasticities	0.209**	0.107	–0.026	0.403

** *p* value lower than 5%; number of bootstraps 1000.

Per capita CO_2 emissions are inelastic with respect to per capita gdp: a 1% increment in per capita gdp of a given country comes with a parallel increase in per capita emissions of only 0.38%. Less than half of this impact, 45%, remains in the same country; in other terms, the emissions in the same country increase by only 0.17%. The impact in its neighbours is also positive, 0.21%, and accounts for the remaining 55%.

Most of the 182 countries in the sample are in the ascending phase of the EKC but some of them already are in the descending phase (increases of per capita gdp come with reductions in per capita emissions). As can be seen in Figure 4, they correspond to highly developed nations in the North Hemisphere. Eleven European countries have a negative total elasticity, where Luxemburg, Iceland and United Kingdom are in the lead, and another large group appears with elasticities near to zero. Sub-Saharan countries and the Indian peninsula are in the other extreme of the ranking, with high positive elasticities, 0.70-0.80 (Burundi and Liberia are in the top).

The ordering is basically the same according to the direct elasticities: negative values for European high-income countries and positive for sub-Saharan and a large group of Asian nations. In a narrow vision of the problem, we could say that the growth model of the last group of nations is not respectful with the environment. That spatial layout remains for the case of indirect effects. The spillovers are negative for 7 European countries, and a large group of highly developed nations have a very low estimated impact on their neighbors. Once again, low income nations in sub-Saharan Africa and in Asia impact significantly on their neighbors.

The last result casts doubts on the importance attributed to strategic interaction as a factor that fosters feedback effects between nations. It is clear that the ideal target for this type of spillover requires transparent parliamentary systems and highly developed nations. However, this group remains overly passive to neighbors according to our estimates. Apparently, in our case the difficulty in accessing the technology and the uneven distribution of social capital are better arguments to explain spatial interaction on CO_2 emissions.

Figure 2. Direct, Indirect and Total elasticities. SARAR model. Period 2004-2011

Figure 2a. Direct elasticities

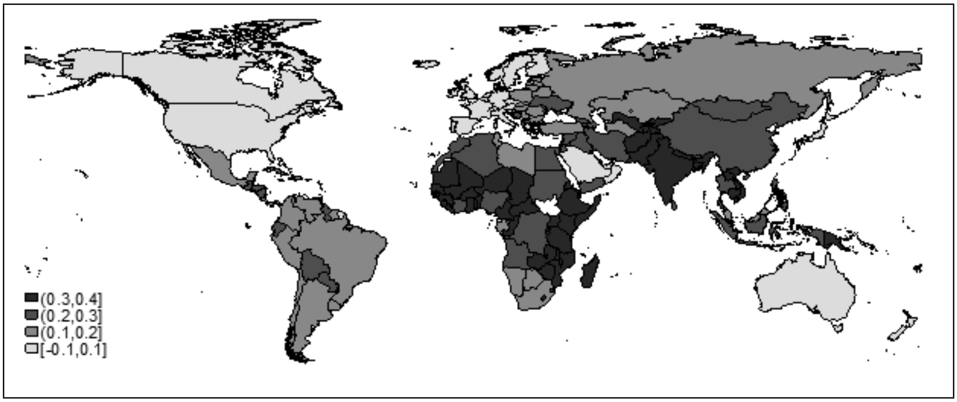


Figure 2b. Indirect elasticities

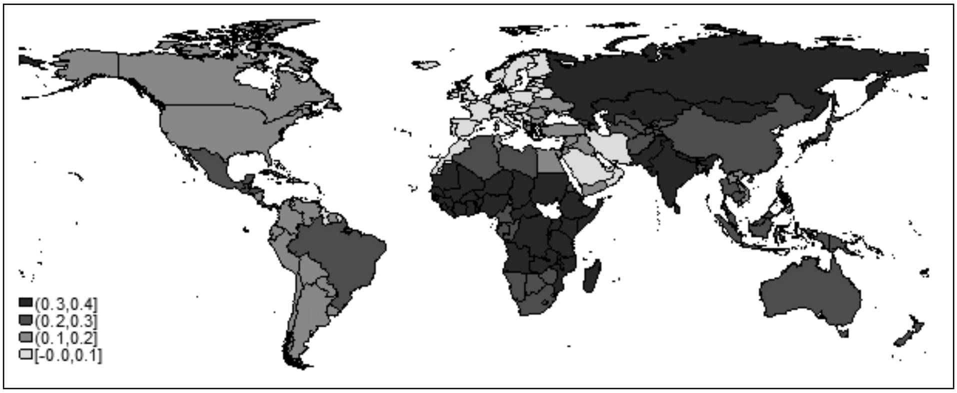
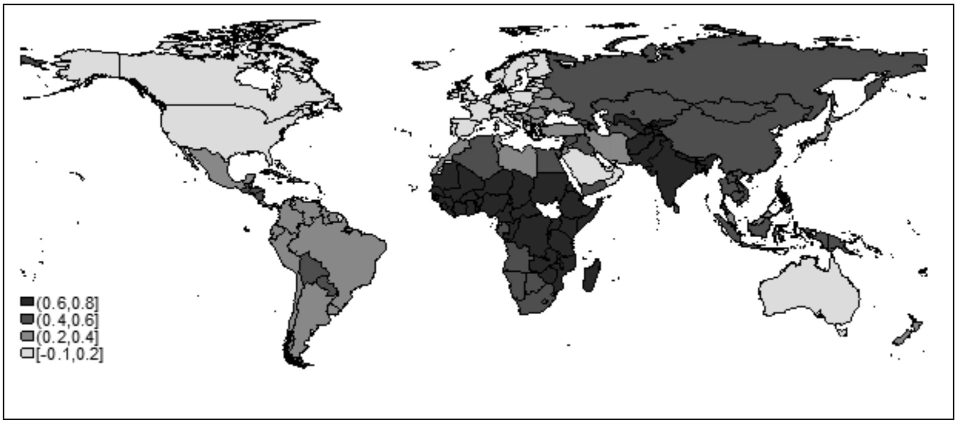


Figure 2c. Total elasticities



4. Empirical results: the cross-sectional case.

The cross-sectional EKC can be seen as restricted version of equation (1). Let us call y_i the (Nx1) vector of CO_2 per capita emissions, in logs, for the time period selected; x_i is the corresponding vector of personal income, also in logs. Then we write:

$$y_i = \beta_0 + \beta_1 x_i + \beta_2 x_i^2 + \varepsilon_i; \quad i = 1,2,...,N \tag{2}$$

The first problem βith (2) is to decide the time period to estimate the equation. The question is not innocuous because we have obtained clear symptoms of structural instability in the year 2004. Table 10 completes the evidence about the impact of the break, now from a pure cross-sectional perspective. The table shows the LRs of the tests of equality of the estimated coefficients (using 5 different cross-sections: 1992, 1995, 2000, 2004 and 2011)[5], for the models that appear in the first column. Let us remind that the LRs compare the likelihood obtained from the model of the null hypothesis (equal parameters in the 5 cross-sections, which must be estimated jointly) vs the sum of the likelihoods obtained from each estimated cross-section in the alternative. The LRs are chi-squared distributed with the degrees of freedom, d.f., indicated in the Table.

Table 10. LRs of equality of cross-sectional estimates

		Period for the NULL HYPOTHESIS		
Model	*d.f.*	*1992-2011*	*1992-2000*	*2004-2011*
LS	3	30.120 (0.000)	47.720 (0.000)	4.720 (0.193)
SLM	4	21.520 (0.000)	50.680 (0.000)	5.068 (0.280)
SEM	4	48.480 (0.000)	53.400 (0.000)	5.340 (0.254)
SDM	6	39.920 (0.000)	56.400 (0.000)	5.640 (0.465)
SARAR	5	42.960 (0.000)	53.500 (0.000)	5.350 (0.375)

p value in parenthesis.

The LRs confirm the break of 2004. The coefficients estimated separately in the 5 cross-sections cannot be taken as equal to those estimated jointly for the whole period. Same conclusion applies for the three cross-sections in the nineties (1992, 1995, 2000); let us note that we did not find symptoms of breaks for the same period using the Bai and Perron (1998) procedure in a panel approach. Contrary, stability characterizes the first decade of the new century: the individual estimates of the two cross-section, 2004 and 2011, are statistically equal. Once again, the impact of the crash of 2007 remains unnoticed for the LRs. That conclusion facilitates our deci-

[5] The number of cross-sections increases the computational burden of the procedure but does not modifies the conclusion shown in the table.

sion: we are going to estimate the cross-sectional models for the average of the period 2004-2011. Main results appear in Table 11 below.

Table 11. Simple cross-sectional estimated models for the average 2004-2011

	LS	*SARAR*	*SDM*	*SLM*	*SEM*
β_0	–14.42**	–12.21**	–11.03**	–12.50**	–11.98**
β_1	2.841**	2.329**	2.082**	2.456**	2.260**
β_2	–0.117**	–0.098**	–0.075**	–0.102**	–0.084**
ρ		0.369**	0.461**	0.235**	
λ		0.133**			0.492**
σ^2	0.65	0.481	0.465	0.513	0.480
Log-likelihood	–207.64	–191.44	–191.98	–198.35	–195.45
SPECIFICATION DIAGNOSTICS					
H_0: Randomness					
Moran's I test	6.073**				
LM against SEM	16.14**				
LM against SLM	4.172**				
LR Tests					
H_0: SLM H_A: SARAR				8.611**	
H_0: SEM H_A: SARAR					2.825*
H_0: SLM H_A: SDM				12.742**	
H_0: SEM H_A: SDM					6.950**

** p value lower than 5%; * p value lower than 10%.
ρ is the coefficient of the spatial lag of the endogenous variable in the equation for the mean.
λ is the coefficient of spatial autocorrelation of the errors.
The estimates of the spatial lags of the exogenous variable in the SDM equation are omitted.

The five equations confirm the EKC hypothesis. The parameters of spatial dependence are positive and significant in all the cases. The plain LS equation is not an acceptable alternative as there are clear signs of omitted spatial effects. The LR that appear at the bottom of the table discard the simple SLM or SEM equations in favor of the SDM or SARAR models. The last two candidates can be compared through, for example, the AIC criterion, which selects the SARAR equation (the AIC of the SARAR is –181.44 and that of the SDM –179.98). In this sense, we are repeating the panel findings.

It is noticeable the wide range of variation of the sequence of turning points corresponding to the five estimates. The minimum corresponds to the SARAR equation, located at $144,734, whereas the maximum appears in the SDM equation, $1,066,614. The disparity is not unusual in the applied literature. Using studies published in the last two decades, the estimated turning points oscillate between $20,647 of Dijkgraaf and Vollebergh (2005); $21,185 in Galeotti *et al*. (2006); $103,840 in Cavlovic *et al*. (2000); $378,000 in Chow and Li (2014); to $4.6 million in Shi (2003). Chow and Li (2014) attribute these extremely high values to the absence of immediate incentives to treat the problem of global pollutants, as in the case of CO_2. According to our experience, the dispersion also points to the sensitiveness of the EKC equation to the estimation algorithms, thus fuelling the scepticism of Panayotou (1993). Let us remind that the turning point estimated from the SARAR equation, for exactly the same period, but in a panel framework is $47,943.

Table 12 reports the direct, indirect, and total elasticities estimated from the SARAR estimated in Table 11; the detail of the elasticities appears in Figure 3.

Table 12. Summary of elasticities. SARAR model. 2004-2011

	Mean	*Standard Dev*	*Minimum*	*Maximum*
Total elasticities	2.373**	0.197	1.961	2.738
Direct elasticities	1.533**	0.153	1.215	1.830
Indirect elasticities	0.840**	0.061	0.693	0.977

** *p* value lower than 5%; number of bootstraps 1000.

According to these estimates, the relation between per capita CO2 emissions and per capita gdp is highly elastic: a 1% increase in the last variable comes with an increase of 2.37% in emissions (let us remind that the relation obtained in the panel case was very inelastic, 0.38%). Moreover, the 182 nations are still in the ascending phase of the EKC curve, and far from the top (which is the turning point). This applies to all the nations in the sample: note that the minimum total elasticity, which corresponds to Luxemburg, is 1.961. In this sense, we should remember that the turning point corresponding to the SARAR equation is $144,734, which is far from current standards. Another point to note is the composition of the total elasticity. The estimates obtained from the cross-sectional SARAR give more importance to internal reactions, so that 65% of the total impact of per capita income on per capita emissions remains in the country and only 35% spills over the neighbours. These percentages were 45% and 55%, respectively, in the case of the panel SARAR equation.

The spatial distribution of the elasticities is not very different from that corresponding to the SARAR panel data model. Once again, a clear North-South pattern emerges where European, high income countries, including North-America and Australia, are in the bottom of the rankings. These nations have the lowest direct elasticities (greater than 1, in any case), indirect elasticities (with a value of 0.693 for the case of Belgium and The Netherlands) and, of course, total elasticities, only slightly

Figure 3. Direct, Indirect and Total elasticities. SARAR model. Period 2004-2011

Figure 3a. Direct elasticities

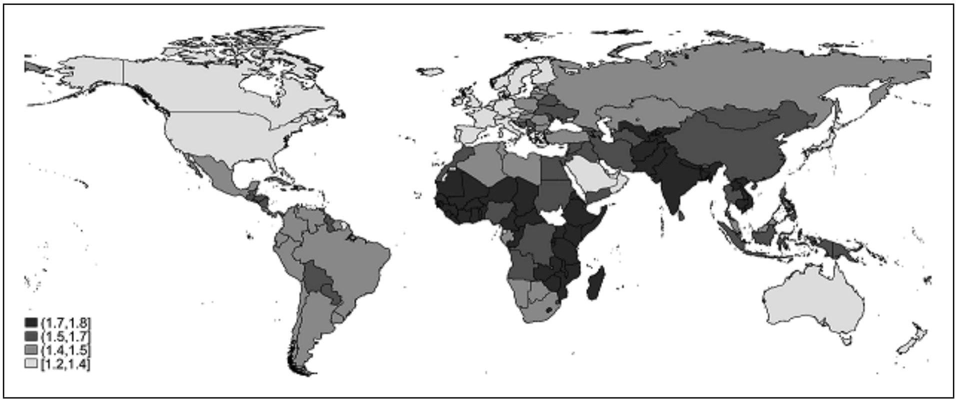


Figure 3b. Indirect elasticities

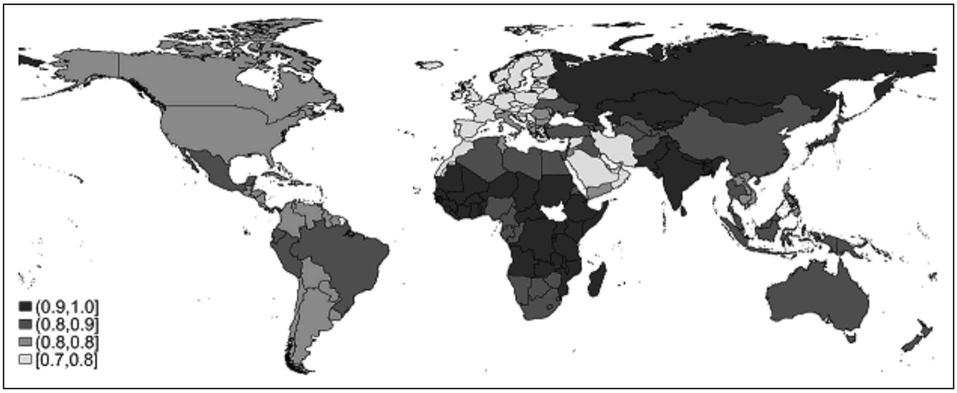
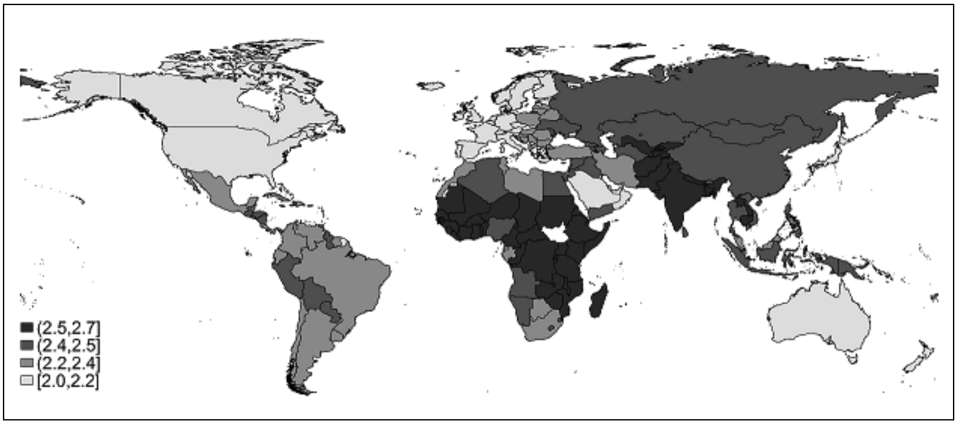


Figure 3c. Total elasticities



less than 2 for the case of Luxemburg and Iceland. The other extreme of the rankings is dominated by sub-Saharan countries and a series of nations in the Indian peninsula.

5. Concluding remarks

The Environmental Kuznets Curve hypothesis conjectures that environmental degradation initially intensifies when per capita income increases but subsides after a certain level of income is reached. This results in an inverted U-shaped curve.

There is abundant literature on the topic that corroborates the existence of an increasing demand for environmental quality, which results in a declining elasticity between per capita emissions and per capita gdp. However, beyond this point, results are very controversial, especially with respect to the predicted turning point. The disparity may be due to the pollutant, to the data used, etc. but also to the methodology. Our study is an example of this dispute. Using simple specifications and data for 182 countries for the period 1992 to 2011, we have obtained estimations sustaining both the EKC hypothesis and its opposite.

According to our experience, it is very important to control for the spatial effects in the equation. The inverted U shaped hypothesis is reinforced when it is estimated in a spatial setting, which means that geography is not neutral because technology and social capital, key elements to manage the emissions issue, are not evenly distributed over space. Strategic interaction is another factor that stimulates spatial interaction, apparently, not very relevant in our case.

However, this is not enough. Heterogeneity caused by omitted factors is a question of the foremost importance. Part of the applied literature on EKC advocates for elaborated testing equations, combining different factors to capture the peculiarities of the units in the sample. However, the practitioner is usually unaware of what kind of peculiarities are relevant for each case. This means uncertainty. Another strand of the literature advocates for simple specifications, stylized versions of the Kuznets curve, using only the principal variables of emissions and income. In spite of the potential problem of omitted variables, we prefer the second approach. The panel framework is well equipped to deal with this issue, i.e., by instrumenting the unobservables. This is not the case of the cross-sectional approach which cannot manage the presence of unobserved effects and whose impact results, very often, in endogeneity problems. We have seen clear symptoms of these inconsistencies in our study: the turning points of the cross-sectional approach seem implausible. Let us add that this is a flaw present in many EKC cross-sectional estimates.

Moreover, there is a third topic that the practitioner should take care: the risk of structural breaks. Specialized literature on spatial data (Lesage and Pace, 2009) defend the idea that a cross-section reflects a kind of long run equilibrium. We do not want to refute this point but only to note that the long run equilibrium, if it exists, will change in case of breaks, which makes crucial the selection of the date for the cross-section. The impact of a break in a panel framework is even worse, because it leads to biased estimates and inconsistent inference. To avoid this problem is convenient to check for the structural stability of the estimates, which can be done easily in a panel data framework.

In sum, we agree with Wagner (2008) when he calls for a careful reflection on techniques. Our sample on EKC related to CO_2 emissions contains a great heterogeneity, spatial effects and structural breaks that must be treated properly. We are not suggesting that our spatial panel data models are the true specifications (if it exists); however, it is out of dispute that panel equations are better equipped than cross-sectional models to deal this kind of problems.

Finally, some authors argue that economic growth may led, by itself, to a reduction in CO_2 emissions. Our results should not be interpreted as giving support to this naïve view. The estimates in the paper tell a history about correlation between two variables, per capita emissions and per capita income, but not about causality. That is a quite different history.

References

Agras, J., and D. Chapman (1999): «A dynamic approach to the Environmental Kuznets Curve hypothesis», *Ecological Economics*, 28, 267-277.

Akbostancı, E., Türüt-Asık, S., and Tunç, G. I. (2009): «The relationship between income and environment in Turkey: Is there an environmental Kuznets curve?», *Energy Policy*, 37, 861-867.

Alam, J. (2014): «On the Relationship between Economic Growth and CO2 Emissions: The Bangladesh Experience», *Journal of Economics and Finance*, 5(6), 36-41.

Al-Mulali, U., Saboori, B., and Ozturk, I. (2015): «Investigating the environmental Kuznets curve hypothesis in Vietnam», *Energy* Policy, 76, 123-131.

Anjum, Z., Burke, P. J., Gerlagh, R., and Stern, D. I. (2014): «Modeling the Emissions-Income Relationship Using Long-Run Growth Rates Using Long-Run Growth Rates», *CCEP Working Paper* 1403, Canberra, Australia: Crawford School of Public Policy, the Australian National University. [Available at] *https://ccep.crawford.anu.edu.au/sites/ default/ files/publication/ccep_crawford_anu_edu_au/2014-08/ccep1403.pdf*.

Anselin, L. (1988): *Spatial Econometrics: Methods and Models*, Dordrecht: Kluwer Academic Publishers.

Apergis, N., and Ozturk. I. (2015): «Testing Environmental Kuznets Curve hypothesis in Asian countries», *Ecological Indicators*, 52, 16-22.

Arrow, K., Bolin, B., Costanza, R., Dasgupta, P., Folke, C., Holling, C. S., Jansson, B. O., Levin, S., Mäler, K.-G., Perrings, C., and Pimentel, D. (1995): «Economic Growth, Carry Capacity, and the Environment», *Science*, 268, 520-521.

Aslanidis, N., and Iranzo, S. (2009): «Environment and development: is there a Kuznets curve for CO_2 emissions?», *Applied Economics*, 41(6), 803-810.

Auffhammer, M., Carson, R., Garin-Munoz, T., and Rich, C. (2000): «Exploring Structural Differences in CO_2 Emissions of China's Provinces», *Working Paper,* San Diego, USA: University of California [Available at] *https://www.researchgate.net/publication/ 255651044_EXPLORING_STRUCTURAL_DIFFERENCES_IN_CO2_EMISSIONS_OF_ CHINA'S_PROVINCES*.

Auffhammer, M., and Carson, R. T. (2008): «Forecasting the path of China's CO_2 emissions using province-level information», *Journal of Environmental Economics and Management*, 55, 229-247.

Azomahou, T., Laisney, F., and Van, P. N. (2006): «Economic development and CO_2 emissions: a non-parametric panel approach», *Journal of Public Economics*, 90(6-7), 1347-1363.

Bai, J. (2010): «Common breaks in means and variances for panel data», *Journal of Econometrics*, 57(1), 78-92.

Bai, J., and Ng, S. (2004): «A Panic Attack on Unit Roots and Cointegration», *Econometrica*, 72, 1127-1177.

— (2010): «Panel Unit Root Tests with Cross-Section Dependence: A Further Investigation», *Econometric Theory*, 26, 1088-1114.

Bai, J., and Perron, P. (1998): «Estimating and testing linear models with multiple structural changes», *Econometrica*, 66, 47-78.

Balaguer, J., and Cantavella, M. (2016): «Estimating the environmental Kuznets curve for Spain by considering fuel oil prices (1874-2011)», *Ecological Indicators*, 60, 853-859.

Baldwin, R. (1995): «Does sustainability require growth?», in Goldin, I., and Winters, L. A. (eds.), *The Economics of Sustainable Development*, Cambridge: Cambridge University Press, pp. 51-78.

Baltagi, B. H. (2013): *Econometric Analysis of Panel Data*, New York: Wiley.

Borghesi, S. (1999): «The Environmental Kuznets Curve: a Survey of the Literature», *European University Institute,* Florence. [Available at] *http://services.feem.it/userfiles/attach/Publication/NDL1999/NDL1999-085.pdf*

Breitung, J. (2000): «The local power of some unit root tests for panel data», in Baltagi, B. H. (ed.), *Advances in Econometrics,* vol. 15: Nonstationary Panels, Panel Cointegration, and Dynamic Panels, 161-178. Amsterdam: JAI Press.

Burnett, J. W., Bergstrom, J. C., and Dorfman, J. H. (2013): «A Spatial Panel Data Approach to Estimating U.S. State-Level Energy Emissions», *Energy Economics*, 40, 396-404.

Cavlovic, T. A., Baker, K. H., Berrens, R. P., and Gawande, K. (2000): «A Meta-Analysis of Environmental Kuznets Curve Studies», *Agricultural and Resource Economics Review*, 29(1), 32-42.

Carson, R. T. (2010): «The environmental Kuznets curve: Seeking empirical regularity and theoretical structure». *Review of Environmental Economics and Policy*, 4(1), 3-23.

Carson, R. T., Jeon, Y., and McCubbin, D. R. (1997): «The relationship between air pollution emissions and income: US Data», *Environment and Development Economics*, 2(4), 433-450.

Chow, G. C., and Li, J. (2014): «Environmental Kuznets curve: Conclusive econometric evidence for CO_2», *Pacific Economic Review*, 19(1), 1-7.

Cole, M. A., Rayner, A. J., and Bates, J. M. (1997): «The Environmental Kuznets Curve: an empirical analysis», *Environment and Development Economics*, 2(4), 401-416.

Costantini, V., and Martini, C. (2006): «A modified environmental Kuznets curve for sustainable development assessment using panel data», *The Fondazione Eni Enrico Mattei Note di Lavoro Series Index,* NOTA DI LAVORO 148, Milano. [Available at] *https://ageconsearch.umn.edu/bitstream/12059/1/wp060148.pdf.*

Danaeifar, I. (2014): «The Estimation parameters of Kuznets Spatial Environmental Curve in European Countries: (A Case Study of CO_2 and PM10)», *Academic Journal of Research in Business & Accounting*, 2(8), 17-25.

Dasgupta, S., Laplante, B., Wang, H., and Wheeler, D. (2002): «Confronting the environmental Kuznets curve» *The Journal of Economic Perspectives*, 16(1), 147-168.

de Bruyn, S. M. (1997): «Explaining the environmental Kuznets curve: structural change and international agreements in reducing sulphur emissions», *Environment and Development Economics*, 2(04), 485-450.

Dijkgraaf, E., and Vollebergh, H. R. J. (2001): «A Note on Testing Environmental Kuznets Curves with Panel Data», Fondazione Eni Enrico Mattei (FEEM) Research Memorandum 63, 2001, Milan. [Available at] *http://econwpa.repec.org/eps/othr/papers/0409/0409001.pdf.*

— (2005): «A Test for Parameter Homogeneity in CO_2 Panel EKC Estimations», *Environmental & Resource Economics*, 32, 229-239.

Dinda, S. (2004): «Environmental Kuznets Curve hypothesis: a survey», *Ecological Economics*, 49, 431-455.

Dogan, E., and Turkekul, B. (2016): «CO_2 emissions, real output, energy consumption, trade, urbanization and financial development: testing the EKC hypothesis for the USA», *Environmental Science and Pollution Research International*, 23, 1203-1213.

Egli, H. (2001): «Are cross-country studies of the environmental Kuznets curve misleading? new evidence from time series data for Germany», *Technical Report* 10, Ernst-Moritz-Arndt University of Greifswald. [Available at] *https://www.econstor.eu/bitstream/10419/48897/1/340741201.pdf.*

EIA (U. S. Energy Information Administration), Environment, Data. [Available at] *http://www.eia.gov/environment/data.cfm.*

Fingleton B., Garretsen, H., and Martin, R. (2012): «Recessionary shocks and regional employment». *Journal of Regional Science*, 52(1):109-133.

Galeotti, M. (2007): «Economic Growth and the Quality of the Environment: Taking Stock. Environment», *Development and Sustainability*, 9, 427-454.

Galeotti, M., and Lanza, A. (1999): «Richer and cleaner? A study on carbon dioxide emissions by developing countries», *Energy Policy*, 27, 565-573.

Galeotti, M., Lanza, A., and Pauli, F. (2006): «Reassessing the environmental Kuznets curve for CO_2 emissions: A robustness exercise», *Ecological Economics*, 57(1), 152-163.

Georgiev, E., and Mihaylov, E. (2015): «Economic growth and the environment: reassessing the environmental Kuznets Curve for air pollution emissions in OECD countries», *Letters in Spatial and Resource Sciences*, 8, 29-47.

Grossman, G. M., and Krueger, A. B. (1991): «Environmental impacts of a North American Free Trade Agreement», *Working Paper* No. 3914, Cambridge MA, USA: National Bureau of Economic Research. [Available at] *http://www.nber.org/papers/w3914.pdf.*

— (1995): «Economic growth and the environment», *Quarterly Journal of Economics*, 110 (2), 353-378.

Hadri, K. (2000): «Testing for stationarity in heterogeneous panel data». *Econometrics Journal*, 3 148-161.

Halkos, G. E., and Tsionas, E. G. (2001): «Environmental Kuznets curves: Bayesian evidence from switching regime models», *Energy Economics*, 23(2), 191-210.

Harris, R., Moffat, J., and Kravtsova, V. (2011): «In search of "*W*"», *Spatial Economic Analysis*, 6(3), 249-270.

He, J., and Richard, P. (2010): «Environmental Kuznets curve for CO_2 in Canada», *Ecological Economics*, 69, 1083-1093.

Heenrink, N., Mulatu, A., and Bulte, E. (2001): «Income inequality and the environment: aggregation bias in environmental Kuznets curves», *Ecological Economics*, 38, 359-367.

Heil, M., and Selden, T. M. (2001): «International Trade Intensity and Carbon Emissions: A Cross-Country Econometric Analysis», *Journal of Environment and Development*, 10, 35-49.

Hill, R., and Magnani, E. (2002): «An exploration of the conceptual and empirical basis of the environmental Kuznets curve», *Australian Economic Papers*, 41(2), 239-254.

Holtz-Eakin, D., and Selden, T. M. (1995): «Stoking the fires? CO_2 emissions and economic growth», *Journal of Public Economics*, 57, 85-101.

Hosseini, H. M., and Kaneko, S. (2013): «Can environmental quality spread through institutions?», *Energy Policy*, 56, 312-321.

Im, K. S., Pesaran, M. H., and Shin, Y. (2003): «Testing for unit roots in heterogeneous panels», *Journal of Econometrics*, 115, 53-74.

IPCC (2013): «Summary for Policymakers», in Stocker, T. F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S. K., Boschung, J., Nauels, A., Xia, Y., Bex, V., and Midgley, P. M. (eds.), *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

IPCC (2014): Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R. K. and Meyer, L. A. (eds.)], Geneva, Switzerland, IPCC, 151 pp.

Islam, N., Vincent, J., and Panayotou, T. (1999): «Unveiling the Income-environment Relationship: An Exploration into the Determinants of Environmental Quality», *HIID Development Discussion Paper* No. 701, Cambridge MA, USA: Harvard Institute for International Development. [Available at] *http://www.cid.harvard.edu/ hiid/701.pdf.*

Iwata, H., Okada, K., and Samreth, S. (2010): «Empirical study on environmental Kuznets curve for CO_2 in France: the role of nuclear energy», *Energy Policy*, 38, 4057-4063.

— (2012): «Empirical study on the determinants of CO_2 emissions: evidence from OECD countries», *Applied Economics*, 44, 3513-3519.

Jaunky, V. C. (2011): «The CO_2 emissions-income nexus: Evidence from rich countries», *Energy Policy*, 39(3), 1228-1240.

Jayanthakumaran, K., Verma, R., and Liu, Y. (2012): «CO_2 emissions, energy consumption, trade and income: a comparative analysis of China and India», *Energy Policy*, 42, 450-460.

Kaika, D., and Zervas, E. (2013a): «The Environmental Kuznets curve (EKC) Theory. Part A: Concept, Causes and the CO_2 emissions case», *Energy Policy*, 62, 1392-1402.

— (2013b): «The Environmental Kuznets Curve (EKC) theory. Part B: critical issues», *Energy Policy*, 62, 1403-1411.

Kang, Y. Q., Zhao, T., and Yang, Y. Y. (2016): «Environmental Kuznets curve for CO_2 emissions in China: A spatial panel data approach», *Ecological Indicators*, 63, 231-239.

Kaufmann, R. K., Davidsdottir, B., Garnham, S., and Pauly, P. (1998): «The determinants of atmospheric SO_2 concentrations: reconsidering the environmental Kuznets curve», *Ecological Economics*, 25(2), 209-220.

Kohler, M. (2013): «CO_2 emissions, energy consumption, income and foreign trade: South African perspective», *Energy Policy*, 63, 1042-1050.

Kunnas, J., and Myllyntaus, T. (2007): «The Environmental Kuznets Curve Hypothesis and Air Pollution in Finland», *Scandinavian Economic History Review*, 55(2), 101-127.

Kuznets, S. (1955): «Economic Growth and Income Inequality» *The American Economic Review*, 45(1), 1-28.

Lau, L., Choong, C., and Eng, Y. (2014): «Investigation of the environmental Kuznets curve for carbon emissions in Malaysia: Do foreign direct investment and trade matter?», *Energy Policy*, 68, 490-497.

LeSage, J., and Pace, R. K. (2009): *Introduction to Spatial Econometrics*, Boca Raton: CRC Press Taylor & Francis Group, LLC.

Lekakis, J. N., and Kousis, M. (2001): «Demand for and supply of environmental quality in the environment Kuznets curve hypothesis», *Applied Economics Letters*, 8, 169-172.

Levin, A., Lin, C., and Chu, C. (2002): «Unit root tests in panel data: Asymptotic and finite-sample properties», *Journal of Econometrics*, 108, 1-24.

Lieb, C. M. (2003): «The environmental Kuznets curve: a survey of the empirical evidence and of possible causes», *Discussion Paper Series* No. 391, Heidelberg, Germany: University of Heidelberg. [Available at] *http://www.uni-heidelberg.de/md/ awi/forschung/ dp391.pdf.*

Lindmark, M. (2004): «Patterns of historical CO2 intensity transitions among high and low-income countries», *Explorations in Economic History*, 41, 426-447.

List, J. A., and Gallet, C. A. (1999): «The Environmental Kuznets Curve: does one size fit all?», *Ecological Economics*, 31, 409-423.

Maddison, D. (2006): «Environmental Kuznets curves: a spatial econometric approach», *Journal of Environmental Economics and Management*, 51(2), 218-230.

— (2007): «Modelling sulphur emissions in Europe: a spatial econometric approach», *Oxford Economic Papers*, 59, 726-743.

Magnani, E. (2000): «The environmental Kuznets curve, environmental protection policy, environmental policy and income distribution», *Ecological Economics*, 32(3), 431-443.

— (2001): «The Environmental Kuznets Curve: development path or policy result?», *Environmental Modelling and Software*, 16, 157-165.

Martin, R. (2012): «Regional economic resilience, hysteresis and recessionary shocks». *Journal of Economic Geography*, 12, 1-32.

McConnell, K. (1997): «Income and the Demand for Environmental Quality», *Environment and Development Economics*, 2, 383-399.

Moomaw, W. R., and Unruh, G. C. (1997): «Are environmental Kuznets curves misleading us? The case of CO_2 emissions», *Environment & Development Economics*, 2(4), 451-463.

Moon, H., and Perron, B. (2004): «Testing for a unit root in panels with dynamic factors». *Journal of Econometrics*, 122, 81-126.

Mur, J., and Angulo, A. (2009): «Model selection strategies in a spatial setting: Some additional results», *Regional Science and Urban Economics*, 39(2), 200-213.

Neumayer, E. (2002): «Can natural factors explain any cross-country differences in carbon dioxide emissions?», *Energy Policy*, 30, 7-12.

Panayotou, T. (1993): «Empirical tests and policy analysis of environmental degradation at different stages of economic development», *Working Paper* WEP 2-22/WP. 238, Geneva, Switzerland: International Labor Organization, Technology and Employment Programme. [Available at] *http://staging.ilo.org/public/libdoc/ilo/1993/ 93B09_31_ engl.pdf.*

— (1997): «Demystifying the environmental Kuznets curve: turning a black box into a policy tool», *Environment and Development Economics* 2(4): 465-484.

— (2000): «Economic Growth and the Environment», *CID Working Paper No. 56, Environment and Development Paper No. 4,* Cambridge MA, USA: Center for International Development at Harvard University. [Available at] *https://www.hks.harvard.edu/ content/download/69258/1249842/version/1/file/056.pdf.*

Pauli, F. (2003): «Environmental Kuznets Curve Investigation Using a Varying Coefficient AR Model», *EEE Working Papers Series No. 12,* Italy: University of Trieste. [Available at] *http://users.ictp.it/~eee/files/WP12_Pauli.pdf.*

Pedroni, P. (1999): «Critical values for cointegration tests in heterogeneous panels with multiple regressors», *Oxford Bulletin of Economics and Statistics*, 61, 653-670.

— (2001): «Purchasing Power Parity Tests in Cointegrated Panels», *Review of Economics and Statistics*, 83, 727-731.

Pesaran, H. (2009): «General diagnostic tests for cross section dependence in panels», *Working Papers in Economics No. 0435,* Cambridge, UK: University of Cambridge, Faculty of Economics.

Pesaran, M. (2007): «A simple panel unit root test in the presence of cross section dependence», *Journal of Applied Econometrics*, 22, 265-312.

Phillips, P., and Perron, P. (1988): «Testing for a unit root in time series regression», *Biometrika*, 75, 335-346.

Poon, J. P. H., Casas, I., and He, C. (2006): «The impact of energy, transport and trade on air pollution in China», *Eurasian Geography and Economics*, 47(5), 568-584.

Pretty, J., and Smith, D. (2003): «Social capital in biodiversity conservation and management», *Conservation Biology*, 18, 631-638.

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.

Roberts, J. T., and Grimes. P. E. (1997): «Carbon Intensity and Economic Development 1962-91: A Brief Exploration of the Environmental Kuznets Curve», *World Development*, 25(2), 191-198.

Roca, J. (2003): «Do individual preferences explain the environmental Kuznets curve?», *Ecological Economics*, 45(1), 3-10.

Runar, B., Karimu, A., and Söderholm, P. (2016): «Convergence in carbon dioxide emissions and the role of growth and institutions: a parametric and non-parametric analysis», *Environmental Economics and Policy Studies*, doi:10.1007/s10018-016-0162-5.

Rupasingha, A., Goetz, S. J., Debertin, D. L., and Pagoulatos, A. (2004): «The environmental Kuznets curve for US counties: a spatial econometric analysis with extensions», *Regional Science*, 83(2), 407-424.

Schmalensee, R., Stoker, T. M., and Judson, R. A. (1998): «1950-2050. World carbon dioxide emissions», *Review of Economics and Statistics*, 80, 15-27.

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(2), 147-162.

Shafik, N., and Bandhopadhyay, S. (1992): «Economic growth and environmental quality: Time-series and cross-country evidence», *World Bank Working Papers,* Washington, USA: WPS 904. [Available at] *http://documents.worldbank.org/curated/en/ 833431468739515725/ pdf/multi-page.pdf*.

Shi, A. (2003): «The impact of population pressure on global carbon dioxide emissions, 1975-1996: evidence from pooled cross-country data», *Ecological Economics*, 44, 29-42.

Soytas, U., Sari, R., and Ewing, B. T. (2007): «Energy consumption, income, and carbon emissions in the United States», *Ecological Economics*, 62, 482-489.

Stern, D. I. (1998): «Progress on the environmental Kuznets curve?», *Environment and Development Economics*, 3, 173-196.

— (2004): «The rise and fall of the environmental Kuznets curve», *World Development*, 32, 1419-1439.

— (2015): «The Environmental Kuznets Curve after 25 years», *CCEP Working Paper No. 1514,* Canberra, Australia: Crawford School of Public Policy, The Australian National University. [Available at] *https://ccep.crawford.anu.edu.au/sites/default/files/ publication/ ccep_crawford_anu_edu_au/2016-01/ccep1514_0.pdf*.

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.

Stern, D. I., Common, M. S., and Barbier, E. B. (1996): «Economic growth and environmental degradation: The Environmental Kuznets Curve and sustainable development», *World Development*, 24 (7), 1151-1160.

Tucker, M. (1995): «Carbon dioxide emissions and global GDP», *Ecological Economics*, 15(3), 215-223.

UN (United Nations): National Accounts: Main Aggregates DataBase, Statistical division. [Available at] *http://unstats.un.org/unsd/snaama/dnlList.asp*.

— United Nations Development Programme, Data. [Available at] *http://hdr.undp.org/en/data-explorer*.

Unruh, G. C., and Moomaw, W. R. (1998): «An alternative analysis of apparent EKC-type transitions», *Ecological Economics*, 25 (2), 221-229.

Vincent, J. R. (1997): «Testing for environmental Kuznets curves within a developing country», *Environment and Development Economics*, 2(4), 417-431.

Wagner, M. (2008): «The carbon Kuznets curve: a cloudy picture emitted by bad econometrics?», *Resource and Energy Economics*, 30, 388-408.

Wang, S. S., Zhou, D. Q., Zhou, P., and Wang Q. W. (2011): «CO_2 emissions, energy consumption and economic growth in China: A panel data analysis», *Energy Policy*, 39, 4870-4875.

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

Yang, G., Sun, T., Wang, J., and Li X. (2015): «Modeling the nexus between carbon dioxide emissions and economic growth», *Energy Policy*, 86, 104-117.

Yavuz, N. Ç. (2014): «CO_2 emission, energy consumption, and economic growth for Turkey: Evidence from a cointegration test with a structural break», *Energy Sources, Part B: Economics Planning and Policy*, 9(3), 229-235.

Zhao, X., Burnett, J. W., and Fletcher, J. J. (2014): «Spatial analysis of China province-level CO_2 emission intensity», *Renewable and Sustainable Energy Reviews*, 33, 1-10.

Zheng, X., Yu, Y., Wang, J., and Deng H. (2014): «Identifying the determinants and spatial nexus of provincial carbon intensity in China: a dynamic spatial panel approach», *Regional Environmental Change*, 14, 1651-1661.

Appendix A. Stochastic properties of the series: main results

This Appendix discusses the stochastic properties of the two series, per capita emissions and per capita gdp, involved in the Kuznets equation. Table A1 summarizes the main results about stationarity while Table A2 focuses on cointegration. Let us remind that y denotes the log of the first variable and x the log transform of the second.

LLC in Table A1 is the Levin, Lee and Chu test (2002) for panel unit root, λ is the Breitung (2000) test, IPS refers to the test of Im, Pesaran and Shin (2003) and H is the Hadri (2000) test. The null hypothesis of the first three test is that there is a unit root in the panels, and the alternative is that some panels are stationary (all panels must be stationary in the Breitung test); the test of Hadri assumes stationarity (for all panels) under the null and the alternative is that some panel are not stationary. The four test are asymptotically normal (*p*-value in brackets) but they are not robust to cross-sectional dependence.

The following tests in Table A1 are designed to account for cross-sectional dependence. This is the case of the CIPS test of Pesaran (2007), based on cross-sectionally augmented ADF regressions, and also of the other two tests that decompose the series into an idiosyncratic term plus a linear combination of common factors. The Moon and Perron (2004) test first de-factorizes the panels to isolate the idiosyncratic components from which the ta and tb tests are obtained. The panel modified Sargan-Barghava test of Bai and Ng (2010) tests for non-stationarity in the idiosyncratic component, through the PMSB test, and also on common factors using the MQf or MQc

Table A1: Panel Unit Root tests for per capita CO_2 emission and per capita GDP

	y	Δy	*Conclusion*	x	Δx	*Conclusion*
LLC	1.8724 (0.9694)	–22.6150 (0.0000)	**I(1)**	1.9957 (0.9770)	–3.9551 (0.0000)	**I(1)**
λ	1.7091 (0.9563)	11.5194 (1.0000)	**I(1)**	1.9957 (0.9770)	–13.2390 (0.0000)	**I(1)**
IPS	2.3604 (0.9909)	–13.5109 (0.0000)	**I(1)**	6.0984 (1.0000)	–9.5571 (0.0000)	**I(1)**
H	42.2937 (0.0000)	–5.1739 (1.0000)	**I(1)**	72.2753 (0.0000)	–15.8997 (1.0000)	**I(1)**
CIPS	–2.0468 (0.9550)	–3.3914 (0.0100	**I(1)**	–1.7679 (0.9902)	–2.9930 (0.0010)	**I(1)**
PMSB	–0.1762 (0.4302)	–1.803 (0.0357)	**I(1)**	–0.8300 (0.2032)	–2.5934 (0.0048)	**I(1)**
MQc	–15.192 n.c.s.t = 2	–15.128 n.c.s.t = 2		–17.907 n.c.s.t = 2	–18.959 n.c.s.t = 2	
ta	–6.0779 (0.0000)	—	**I(0)**	–7.3052 (0.0000)	—	**I(0)**
tb	–4.6108 (0.0000)	—	**I(0)**	–7.3653 (0.0000)	—	**I(0)**
n.c.f.	2	2		2	2	

of Bai and Ng (2004). n.c.f. indicates the number of common factors determined by the Akaike Information Criteria and n.c.s.t the number of common stochastic trends identified for the common factors. The null hypothesis in all the cases is that there are unit roots in the respective component. PMSB, CIPS, ta, and tb tests are asymptotically distributed as standard normals under the null, but the distribution of MQc is not standard. All the tests in Table A1 include individual effects and a common time trend.

Overall, the conclusion is that the log of the two panel series has a unit root, which disappears after differencing; only the Moon-Perron tests ta and tb not agree.

The two variables, as shown in Table A2, are cointegrated. Pedroni (1999) develops two group of cointegration tests; the panel tests are based on pooling different estimates across members while the group statistics simply average the estimates. The variance ratio is a nonparametric right-sided test, while the others, left-sided, can be seen as slight variations of the Dickey-Fuller test, in the case of ADF, and the Phillips and Perron (1988) *t* and ρ tests. The four converge asymptotically to the normal distribution. The P statistics of Westerlund (2007) pool information over all the cross-sectional units whereas the G statistics are obtained as weighted averages of individual estimates. They are also asymptotically normally distributed but the pvalues have been obtained after 500 bootstraps; these *p* values are robust to cross-sectional dependence. All the tests include individual effects and a common time trend; finally, maximum truncation lags are set to 3 and determined using data dependent criteria. Let us remind that the null hypothesis for the tests of Pedroni and Westerlund is no cointegration.

The conclusion of cointegration appears robust: six of the seven cointegration test of Pedroni point in that direction, the same that three of the four tests of Westerlund. We have not a clean cut explanation for the discrepancies, which are possibly related to the short time span (20 observations) and wide cross dimension (182 countries) of our study.

Table A2: Panel Cointegration tests for per capita emission and per capita GDP

Pedroni (1999) tests			
	Panel statistics		*Group statistics*
Variance ratio	5.062		
rho	–2.844*	rho	–17.321*
t	–5.696*	t	–40.472*
ADF	–4.976*	ADF	–15.475*

* means 5% statistically significant.

Westerlund (2007) tests			
Panel statistics		*Group statistics*	
Pt	–2.8234 (0.0022)	Gt	–2.6952 (0.0041)
Pc	–3.4705 (0.0000)	Ga	1.5396 (0.9382)