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CO_2 EMISSIONS AND ECONOMIC ACTIVITY:

HETEROGENEITY ACROSS COUNTRIES AND NON STATIONARY SERIES[1]

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Abstract

This paper explores the homogeneity of the functional form, the parameters, and the turning point, when appropriate, of the relationship between CO_2 emissions and economic activity for 31 countries (28 OECD, Brazil, China, and India) during the period 1950 to 2006 using cointegration analysis. With a sample highly overlapped over time between countries, the result reveals that the homogeneity across countries is rejected, both in functional form and in the parameters of long term relationship. This confirms the relevance of considering the heterogeneity in exploring the relationship between air pollution and economic activity to avoid spurious parameter estimates and infer a wrong behavior of the functional form, which could lead to induce that the relationship is reversed when in fact it is direct.

Keywords: Bound testing, cointegration, CO_2 emissions, environmental Kuznets curve, heterogeneity.

JEL codes: C32, O13, Q53, Q56.

1. Introduction

The Environmental Kuznets Curve (EKC) hypothesis comes from Kuznets (1955), where an inverted-U shaped relationship is supposed between income inequality and income level. The EKC hypothesis suggests the existence of an inverted-U shaped relationship between environmental degradation and income level.

Grossman and Krueger (1991) argued that there are three channels that explain this path. In early stages of economic growth, the greater requirement of natural resources and waste generation increases environmental degradation (scale effect). This growing path might lead to changes in the economic structure towards less polluting activities (composition effect), which along with the increase in the capacity of higher income countries to face technological substitution towards less polluting processes (technological effect) would lead to a turning point in the relationship and to the decreasing section of the curve. Therefore, the transition from the increasing to the decreasing section of the curve in the relationship between environmental degradation and economic activity would arise when the composition and technological effects worked in the indicated direction and overcame the scale effect[2].

[2] The existence of composition and technological effects do not necessarily imply a result as the one suggested by the EKC hypothesis. For this to be the case, it is required that the composition effect involves a reduction of polluting sectors in absolute and not only in relative terms. As for the technological change, it might sometimes involve new processes with new (and sometimes unknown) pollutants or efficiency improvements leading to the increase of extractive or other environmentally damaging activities (Roca and Padilla, 2003). Therefore, it depends on the type of technological and composition change that these effects compensate or reinforce the scale effect for a specific pollutant.

However, an EKC can be driven by different underlying factors, so that the relation behind the hypothesis can be generated by different structural models (Perman and Stern, 1999). The literature highlights the distribution of power (Torras and Boyce, 1998), income-elasticity of the demand for environmental quality (McConell, 1997; Dasgupta et al. 2002), environmental regulation and international agreements (de Bruyn, 1997) or structural transitions, like the oil price shocks in the 1970s (Moomaw and Unruh, 1997). Also, an EKC can be reached by individual countries through the pollution haven hypothesis (Stern et al., 1996; Cole et al., 1997). In this way, although an inverted-U relationship can be empirically shown, this can be a statistical result stemming from other factors, which might imply that the observed relationship between environmental degradation and economic growth is spurious. Moreover, these factors might vary across countries and be different for different pollutants.

Earlier works ignored that the relationship between environmental degradation and income can be heterogeneous across countries (or regions), both in the functional form as well as the parameters and the turning point (Grossman and Krueger, 1991 and 1994; Shafik and Bandyopadhyay, 1992; Selden and Song, 1994; Carson et al. 1997; Cole et al. 1997 and Vincent, 1997). This issue was first studied in the late 1990s and early 2000s (Perman and Stern, 1999 and 2003; List and Gallet, 1999; Dijkgraaf and Vollebergh, 2001; Martínez-Zarzoso and Bengochea-Morancho, 2003 and 2004 and Dijkgraaf et al., 2005). Following the same concerns, a series of analyses of the EKC at national level has emerged, (among them Vincent, 1997; de Bruyn et al., 1998; Moomaw and Unruh, 1998; Friedl and Getzner, 2003; Lekakis, 2000; Roca et al., 2001; Decon and Norman, 2004; Egli, 2004; Hung and Shawn, 2004; Shen, 2006; Halicioglu, 2008; Piaggio, 2008; Song et al., 2008; and Wang, 2009).

Moreover, until the study of Perman and Stern (1999), the statistical properties of the data employed were not taken into consideration. The analysis using non-stationary series has to be carried out taking into account this characteristic.

The traditional EKC approach not only ignores that economies with the same level of activity might present heterogeneous functional forms with respect to the relationship between income and environmental degradation, but also assumes parameter homogeneity in this relationship across countries. An EKC estimated from cross-section or panel data when the series are not or are hardly overlapped over time across countries can simply reflect the juxtaposition of a positive relationship between environmental degradation and income in rich countries with a negative one in developing countries, and not a relationship operating for both kinds of countries (Vincent, 1997). This problem can be solved if the panel data set has overlapped observations for large periods (Egli, 2004). However, this would not solve the problem of assuming homogeneity in the functional form of the relationship between environmental degradation and income among countries.

In light of the above, the analyses that assume homogeneity in the functional form and in the parameters across countries might in fact not reflect the behavior of the relationship between environmental degradation and income for these at the individual level. So, the conclusions that, after certain point, environmental degradation decreases with greater economic activity for the more developed countries might be wrong. Consequently, more attention should be paid to individual countries behavior in order to assess the possible benefits of the increase in economic activity on environmental quality for each country (de Bruyn et al., 1998). To impose *a priori* the constraint of homogeneity between countries in the functional form and the parameters might be a statistical device more than a model that appropriately approximates reality. Carson (2010) argues that the analysis should distinguish between a "weak" version of the EKC hypothesis, for a particular political jurisdiction, and a "strong" one, applying for the different political jurisdictions.

The objective of this paper is to analyze the homogeneity in the functional form and parameters among countries in the long-run relationship between carbon dioxide emissions (CO_2) and economic activity. The analysis is carried out for 31 countries (28 OCDE countries, Brazil, China and India) over the period 1950–2006; such a period presents a high degree of overlapping across the series. First, the functional form homogeneity will be tested through the estimation of the relation for each individual country. The time period considered in this paper is longer than the one from previous studies. This is very important, because a longer period increases the overlap among countries that have similar economic activity level but might have heterogeneous functional forms. For those countries with homogeneous functional forms the homogeneity in the parameters of the long run relationship would be tested, allowing variations among them in both short term adjustments and in the rate of convergence to the long run relationship. Also, homogeneity in the turning point among the countries that presents one would be tested. The use of cointegration techniques would avoid the possibility of a spurious relationship between CO_2 emissions and economic activity.

In the next section, the conceptual framework of the EKC hypothesis and the relationship between economic growth and environmental degradation adjusted to our analysis is presented. Section 3 presents the methodology and data used. Section 4 details the analysis results. Section 5 presents the final remarks.

2. Conceptual framework

The EKC hypothesis arises from a reduced model specification. Therefore, it can be the result of one or more different structural relationships, because it is an empirical phenomenon. So, this is in fact an apparent relation analysis between environmental degradation and economic activity. In line with previous works, the reduced form model relates environmental degradation level with economic activity for each country, which can follow a lineal, quadratic or cubic functional form:

$$(1) \qquad E_{it} = \alpha_i + \beta_1 Y_{it} + \beta_2 Y_{it}^2 + \beta_3 Y_{it}^3 + \varepsilon_{it}$$

where *E* denotes the indicator of environmental degradation (per capita) and *Y* is income (per capita). Subscript *i=1,…, N* indicates subjects (countries), subscript *t = 1, …, T* is the time period indicator, and ε is the error term normally distributed. The correct functional form for each country can be specified from the equation above.

Following Perman and Stern (1990 and 2000) and Carson (2010), a "weak" EKC would result if $\beta_{1i}>0$, $\beta_{2i}<0$, and $\beta_{3i}=0 \ \forall \ i$, but these parameter would have different values for different countries. A "strong" version would result if $\beta_{1i}= \beta_1$ *and* $\beta_{2i}= \beta_2 \ \forall \ i$.

In the same way, an N relation would result if $\beta_{1i}>0$, $\beta_{2i}<0$, y $\beta_{3i}>0$, where there would exist a second turning point. Finally, the relationship will be monotonous (increasing or decreasing) when $\beta_{2i}= \beta_{3i}= 0$. A "strong" version of a monotonous relationship would occur when $\beta_{1i}= \beta_1 \ \forall \ i$.

Empirically, any of the functional forms (lineal, quadratic or cubic) can be reached, depending on the country. Therefore, the functional form that best fits each country would be determined before the parameter homogeneity analysis.

When a quadratic or cubic functional form is determined, it is also relevant to study the turning point homogeneity among countries. If different countries' turning point homogeneity is not rejected, it can be the case that countries with different rates in the relationship will achieve the turning point at the same economic activity level. This factor is also relevant, because there could be support for directing policy making toward reaching the turning point, no matter what the path is. Therefore, the threshold from which environmental degradation is too high or irreversible would be a relevant piece of information to interpret the policy implications of supporting the EKC hypothesis for each country. It could be that from certain level of degradation it may not be feasible to revert environmental damage (Panayotou, 1993) or that the increase in economic activity led to a rate of use of resources which did not allow their regeneration or that the waste was dumped on the ecological system at a higher rate than its capacity to carry it (Arrow et al., 2005).

There are not theoretical foundations that support the functional form and parameters homogeneity restriction for different countries. Perman and Stern (1999 and 2003) estimate a dynamic specification with panel data to test the homogeneity of the parameters in the relationship between SO_2 and income for 74 countries between 1960 and 1990 assuming a quadratic functional form. They reject parameter homogeneity both for the whole sample of countries as well as for two subsets (OECD and non-OECD countries). Martínez-Zarzoso and Bengochea-Morancho (2003 and 2004) apply the same methodology in order to explore the homogeneity of the functional form in the case of CO_2 emissions for 19 Latin American countries and 22 OECD countries respectively. They conclude that, while both subgroups represent heterogeneous behaviors among countries, the first group is best assembled by a quadratic model, while the second might be gathered by a cubic one.

List and Gallet (1999) test homogeneity of both functional form and parameters in the cases of NO_X and SO_2 emissions for 48 USA states over 1929–1994. They conclude that while a quadratic relationship is confirmed for all of them, the parameters are heterogeneous among states.

Finally, Dijkgraaf and Vollebergh (2001) and Dijkgraaf et al. (2005) study the homogeneity in the case of CO_2 emissions for a 24 OECD countries panel between 1960 and 2000. They test the homogeneity of the parameters for the cubic specification and employ semi and non parametric techniques to study the homogeneity of the functional form. They conclude that the relationship is heterogeneous among countries, and do not find groups with more than five members the relationship of which is homogeneous. As for the functional form of the estimated relationship, it depends on the balance in the sample between countries with an expected inverted-U relationship and those with an expected one that is linear.

Until the late 1990s the empirical literature ignored the stationary analysis of the variables, which should lead to the estimation of spurious relations (Grossman and Krueger, 1991 and 1994; Shafik and Bandyopadhyay, 1992; Carson et al. 1997; Cole et al. 1997; Vincent, 1997 and de Bruyn et al., 1998). Both environmental degradation and income series used to be non-stationary (that is to say, their parameters are not constant throughout time). Therefore, employing the variables in levels —without any stationary transformation— for the estimation of a long run relationship between environmental degradation and income would result in non robust estimators. This would make the application of inference tests impossible, and while the relationship can be spurious, at least the series were cointegrated (Enders, 2004).

The analysis of the series stationarity and cointegration when these are non stationary have been developed by various authors in the last decade, both for panel data and for individual countries studies (Perman and Stern, 1999 and 2003; Lekakis, 2000; Roca et al., 2001; Friedl and Getzner, 2003; Egli, 2004; Dinda and Coondoo, 2006; Wagner, 2008; Halicioglu, 2008; Piaggio, 2008; Song et al., 2008; Lee and Lee, 2009 and Wang, 2009).

3. Methodology and data

The aim of this paper is to test the functional form, parameters, and turning point when appropriate, homogeneity across countries in the relationship between CO_2 emissions and economic activity. In this section the empirical strategy used is first described, and data sources are shown.

3.1. Empirical strategy

The EKC hypothesis refers to a long run phenomenon, and thus might be estimated via cointegration analysis. Pesaran et al. (2001) develops the bound testing (BT) for the cointegration analysis of the relationship of variables in levels. For this paper purpose, BT presents some advantages with respect to more frequent cointegration tests (Engle and Granger, 1987; Johansen and Juselius, 1990 and Johansen, 1991) because it can be applied when there is uncertainty about the degree of integration of the series involved, where all of them can be I(1), I(0) or a combination of both[3]. Granger and Hallman (1991)

[3] I(q) indicates the degree of integration of the series, being the q^{th} difference of the series a stationary transformation.

show that monotonous non linear transformations of I(1) series are also I(1). It is also hard to believe, understand and interpret long run series with order higher than one. Therefore, the empirical strategy followed in this study will allow to determine the existence of a stationary linear combination of the variables involved that led to a long run relationship. This approach has been previously employed by Perman and Stern (2003) and Iwata et al. (2009 and 2010).

Equation (1) can be written as a dynamic model ADRL (p,p_1,p_2,p_3) for a single country in an Error Correction Model (ECM) form:

(2)$\Delta E_t = \sum_{j=1}^{p} \theta_j \Delta E_{t-j} + \sum_{j=0}^{p_1} \xi_j \Delta Y_{t-j} + \sum_{j=0}^{p_2} \delta_j \Delta Y_{t-j}^2 + \sum_{j=0}^{p_3} \gamma_j \Delta Y_{t-j}^3 + \alpha_0 E_{t-1} + \alpha_1 Y_t + \alpha_2 Y_t^2 + \alpha_3 Y_t^3 + \mu + \varepsilon_t$

Pesaran et al. (2001) propose to contrast the hypothesis of non existence of a long run relationship between the variables in levels (no cointegration hypothesis), $H_0: \alpha_0 = \alpha_1 = \alpha_2 = \alpha_3 = 0$, against the alternative hypothesis that there exists a long run relationship between them, $H_1: \alpha_0 \neq 0,\ \alpha_1 \neq 0,\ \alpha_2 \neq 0,\ \alpha_3 \neq 0$, employing the usual Wald test[4]. Critical value ranges are provided by the authors, comprising all the possible classifications of the series in I(1), I(0) or combinations of both. Therefore, if the computed statistic is greater than the upper bound, the hypothesis that there exists a long run relationship between the variables would not be rejected. It will be rejected in the case that the

[4] For the linear model $y = X\beta + \epsilon$, the linear restriction $H_0: R\beta - r = 0$, where R is a known matrix q x k, and r is a vector of q dimension, the Wald statistic may be written $W = (Rb - r)'(R_s(X'X)^{-1}R_s')(Rb - r) \sim \chi^2(q)$, that if the lags ε are normally and identically and independently distributed, then the statistic is distributed as $F_{q,n-k+a}$.

computed statistic is lower than the lower bound. The test is not conclusive when the statistic is within the bounds. Moreover, the BT is very sensitive to the lags included, so that, following Pesaran et al. (2001), we will estimate the Wald statistic considering several number of lags.

The dynamic model shown in equation (2) allows to overcome the issue that deviations from the long run equilibrium are not instantaneously corrected (as suggests the static specification presented in equation (1)). This assumption is more plausible (and will be empirically tested), as it might be reasonable to expect that the adjustment between environmental degradation and economic activity to be slow (Perman and Stern, 1999).

Once the existence of a long run relationship is tested, we will proceed to estimate the following transformation of the ECM posited in equation (2) employing Non-Linear Least Squares (NLLS):

(3)

$$\Delta E_t = \sum_{j=1}^{p} \theta_j \Delta E_{t-j} + \sum_{j=0}^{p_1} \xi_j \Delta Y_{t-j} + \sum_{j=0}^{p_2} \delta_j \Delta Y_{t-j}^2 + \sum_{j=0}^{p_3} \gamma_j \Delta Y_{t-j}^3 + \alpha_0 [E_{t-1} - \mu^* - \beta_1 Y_t - \beta_2 Y_t^2 - \beta_3 Y_t^3] + \varepsilon_t$$

Where $\beta_1 = -\frac{\alpha_1}{\alpha_0}$; $\beta_2 = -\frac{\alpha_2}{\alpha_0}$; $\beta_3 = -\frac{\alpha_3}{\alpha_0}$ y $\mu^* = -\frac{\mu}{\alpha_0}$. The number of lags, p, p_1, p_2 and p_3 are independently chosen for each country, following from general to particular criteria (Hall, 1991)[5]. The term within brackets represents the error correction term (ECT). The interpretation of its parameters should be cautious because when the term is normalized with respect to variable *E*, the sign of the other variable coefficients is opposite to the expected one. Besides the improvement in the consistence provided by the estimation method, this specification, presents three more advantages: i) it allows to identify the long run relationship, the short run dynamic and the coefficient of adjustment to the equilibrium relationship (α), ii) if the series in levels are cointegrated, the ECM is a linear combination of stationary variables. Then, estimations are robust, and conventional inference procedures can be applied, and iii) this specification allows testing different restrictions among individuals (Perman and Stern, 1999 and 2003).

Cointegration analysis and the estimation of the long run relationship by means of the ECM should be reiterated for the cubic specification (equations (2) and (3)), quadratic (when $\beta_3 = 0$ and $\gamma_j = 0 \; \forall \; j = 1 \dots p_3$)) and linear (when $\beta_2 = \beta_3 = 0$ and $\delta_i = \gamma_j = 0 \; \forall \; i = 1 \dots p_2$ and $j = 1 \dots p_3$). That way, the best functional form of the long run relationship between CO_2 emissions and income level for each single country will be determined (if one exists). Those countries that do not satisfy the BT cointegration test, or that the model estimated is not satisfactory for the functional form that the BT indicates, a unit roots analysis through the Augmented Dickey-Fuller test (ADF) and the cointegration analysis through Engel-Granger test (1987) should be carried out (Enders, 2004). Then, when the series are I(1) and are cointegrated the ECM may be estimated for each

[5] A general model for a given *p*, p_1, p_2 and p_3 value, large enough, is specified. Then, the lag is reduced, in an independent way for each of them, determining the value of each of them for the lag of greater degree statistically significant.

specification. Engle-Granger cointegration test is seen as the most appropriate one for the present analysis, because a priori we explore the existence of only one cointegration relation. The test proposed by Johansen and Juselius (1990) and Johansen (1991) becomes complex in the presence of non linear transformations of one of the variables, as it allows for the existence of more than one cointegration relationship.

The present specification does not tackle the omission of relevant variables problem. List and Gallet (1999) argue that a reduced form model allows to measure the direct and indirect relationship between economic activity and environmental degradation, so that the inclusion of additional variables would distort the analysis. Therefore, it is not possible to make causality conclusions based on a reduced form model. So, it is not possible to assess what causes the relationship to exist. This kind of analysis allows the study of apparent elasticities, not being an analysis of the determinants of environmental pollution. As it is a uniequational specification, it does neither solve the problem of a possible feedback between the variables. However, as it is developed through a cointegration analysis, the estimated parameters will be superconsistent, not being affected by the endogeneity bias of the variables (Veerbek, 2005).

The specification of the ECM for the analysis of this relationship is employed by Perman and Stern (1999 and 2003) for SO_2 emissions, and Martínez-Zarzoso and Bengochea-Morancho (2003 and 2004) and Dinda and Condoo (2006) for CO_2 emissions, all of them working with panel data. Egli (2004) for diverse kind of contaminants and Iwata et al. (2009 and 2010) for CO_2 emissions employed it for individual countries, and Haciglou (2008) and Piaggio (2008), who study CO_2 emissions for individual countries but in a multi equation specification.

Once the correct functional form is specified and the long run relationship through the ECM is estimated, the homogeneity of parameters among countries with equal functional form will be studied, allowing the short run coefficients to be different among countries, as well as the quantity of lags in each one of them. This will be tested computing confidence intervals (CI)[6] for the parameters of the long run relation, grouping those countries with same functional form the CI of which overlap. The same exercise is carried out with respect to the coefficient of adjustment of disequilibria from the long run relationship (*α*).

A similar strategy is followed for testing the turning point homogeneity. The turning point for countries with a quadratic functional form equation (3) is given by $\hat{\theta} = -\frac{\widehat{\beta_1}}{2\widehat{\beta_2}} \sim \text{Normal}\left(\hat{\theta}, V(\hat{\theta})\right)$[7], given the distribution of parameters β_1 and β_2. From this, the turning point CI will be computed for the turning point of those countries whose best adjustment is the quadratic functional form. A similar procedure might be developed with respect to those with cubic functional form.

[6] IC: $\left[\hat{\beta} \pm z_{\alpha/2}\frac{s_{\hat{\beta}}}{\sqrt{n}}\right]$, where $s_{\hat{\beta}}$ is the standard deviation associated to the estimated parameter $\hat{\beta}$, $(1-\alpha)$ is the confidence level, and n is the sample size.

[7] Employing the Delta Method, following Hayashi (2000: pp. 93–94) and Greene (2003, p. 70), $As.Var\,(\hat{\theta}) = \begin{pmatrix} \frac{-1}{2\beta_2} & \frac{\beta_1}{2\beta_2^2} \end{pmatrix} \begin{pmatrix} \sigma_{\beta_1\beta_1} & \sigma_{\beta_1\beta_2} \\ \sigma_{\beta_2\beta_1} & \sigma_{\beta_2\beta_2} \end{pmatrix} \begin{pmatrix} \frac{-1}{2\beta_2} \\ \frac{\beta_1}{2\beta_2^2} \end{pmatrix}$

2.2. Data

The analysis takes into account 31 countries (28 OECD countries[8], Brazil, China and India) between1950–2006[9]. This time period is longer than the one from previous studies on the homogeneity of the parameters for CO_2 emissions, which increases the possibility of taking into account countries with overlapped income levels but heterogeneous paths. Moreover, the sample contains almost all countries (except Iceland and Luxembourg) committed to quantitative limits in CO_2 emissions through Annex B of the Kyoto Protocol (United Nations, 1998).

CO_2 emission data is published by the Carbon Dioxide Information Analysis Center (CDIAC) (Boden et al., 2009). It is consistent with the one of the World Bank (2005) for the period 1960–2005, allowing to take into account ten more years. CO_2 emissions are measured in metric tons of CO_2. Logarithmic transformation of emissions per capita (co2pc) is employed.

Economic activity at national level employed are estimated and transformed to 1990 Geary-Khamis dollars (which corrects by purchasing power parity, PPP) by Madison (2003), updated to 2005 by the same author for 155 countries. The

[8] Australia, Austria, Belgium, Canada, former Czechoslovakia (after 1992 the values for Czech Republic and Slovakia are added), Denmark, Finland, France, Germany (for the period 1950–1990 the information for the German Federal Republic and the German Democratic Republic are added), Greece, The Netherlands, Hungary, Ireland, Italy, Japan, South Korea, Mexico, Norway, New Zealand, Poland, Portugal, Spain, Sweden, Switzerland, Turkey, UK, USA, and former Soviet Union (from 1992 the values of Estonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Russia, Tajikistan, Turkmenistan, Ukraine and Uzbekistan are added). Two OECD countries, Iceland and Luxembourg, are excluded due to lack of information for the entire period.

[9] Except for Belgium, for which we took the period 1962–2006, as it presented atypical values for the two first years of the sample.

National Accounts System was set up in 1950 in various countries, which allows having reliable information. Logarithmic transformation of per capita growth domestic product for the variable in levels, and its quadratic and cubic transformation are used (gdppc, gdppc2, and gdppc3, respectively).

4. Results

In this section, first the cointegration analysis through the BT test is carried out to determine the existence of a long run relation between the variables and the more adequate functional form for each of the countries. Second, the analysis of the parameters of the long run relation homogeneity between countries, of the turning point and of the ECT coefficient is performed through confidence intervals construction.

4.1. Cointegration analysis

Following Pesaran et al. (2001) we will carry out the contrast several times, including up to four lags, due to the sensitiveness of the analysis to the quantity of lags included. Though the quantity of lags seems high when working with annual data, the length of the series allows it. Table I summarizes the results of the F-statistic of the Wald test for the linear, cubic and quadratic specification of equation (2).

Some countries of the sample allow for the existence of a long run relationship for the variables of interest for more than one functional form. This might result, for example, from quadratic forms that have not achieved the maximum, or that have just surpassed it, or cubic forms with tiny decreasing sections might be approached through linear models. Therefore, the adequate functional form for each country would be determined from the cointegration analysis jointly with the estimation of the equation (3) for each one of the functional forms in the countries confirming the existence of a long run relationship[10].

As shown in Table I, BT rejects the null hypothesis of no cointegration for Australia (linear and quadratic specification), Austria (quadratic and cubic), former Czechoslovakia (linear and quadratic), Denmark (quadratic and cubic), Germany (cubic), Greece (linear and quadratic), Hungary (linear and cubic), Ireland (linear, quadratic and cubic), Italy (linear, quadratic, and cubic), Japan (quadratic), South Korea (linear, quadratic, and cubic), Poland (linear), Portugal (quadratic and cubic), Switzerland (linear, quadratic and cubic), Turkey (quadratic and cubic), former Soviet Union (quadratic) and China (linear and cubic).

When the BT is inconclusive, Iwata el al. (2009 and 2010) argue that the non existence of a cointegration relationship may be rejected or not according to the test of significance of the parameter of adjustment (α) of equation (3). The BT is not conclusive for Belgium (quadratic), Canada (quadratic and cubic), former Czechoslovakia (cubic), Finland (linear, quadratic and cubic), Greece (cubic), the Netherlands (quadratic and cubic), Hungary (quadratic), Japan (cubic),

[10] For the choice of the functional form we employed different statistical and analytical tools, such as the *t-statistic* significance of the parameters, the Schwartz information Criteria, and taking into account if the turning point estimated is lower than the maximum level of income reached by each country.

Mexico (linear), Norway (quadratic and cubic), New Zealand (quadratic and cubic), Spain (quadratic), Sweden (linear and cubic), former Soviet Union (linear and Cubic), China (quadratic) and India (quadratic). Finally, the test indicates that there is not a long run relationship for any functional form for France, United Kingdom, USA and Brazil.

Table I - CO_2 emissions and economic activity bound testing cointegration test

	Lineal[1]					Quadratic[2]					Cubic[3]				
Lags	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
AUS	4.09[b]	7.66**	1.02	0.80	0.72	5.12**	4.93**	1.35	0.72	0.84	2.31	0.51	2.03	1.82	NA
AUT	1.50	0.86	1.17	1.25	0.78	4.25*	2.87	3.92[b]	2.15	1.62	3.31[b]	2.10	4.11*	3.86*	2.93[b]
BEL	4.91*	2.96	2.37	1.73	0.89	9.78***	3.20[b]	2.07	1.65	1.36	9.31***	1.70	2.17	1.14	0.93
CAN	0.65	0.49	0.78	1.50	2.14	2.57	3.08	1.54	1.88	3.53[b]	2.35	3.40[b]	2.19	1.54	2.81[b]
CZE	8.01***	3.37	3.12	3.96	5.1*	4.63*	2.87	2.08	1.96	1.99	3.14[b]	1.73	1.39	0.36	0.56
DEN	2.16	2.14	1.75	1.73	1.42	9.66***	5.53**	5.84**	7.23**	3.27[b]	7.05***	4.61**	4.98**	5.79***	3.58[b]
FIN	2.82	2.63	2.81	4.54[b]	3.71	3.22[b]	2.58	2.19	1.61	1.25	2.81[b]	2.46	2.95[b]	1.90	1.32
FRA	1.21	1.49	1.55	2.17	1.69	1.84	1.79	2.07	1.78	1.01	2.22	1.53	2.51	3.03[b]	2.75[b]
GER	1.39	0.36	0.54	0.62	0.75	1.33	1.92	1.67	1.23	1.26	3.89*	2.62	2.26	2.23	0.80
GRE	4.27[b]	5.07*	6.27**	7.58**	7.45**	5.64**	6.15**	6.35**	4.43**	5.30**	2.88b	2.69	2.18	1.37	1.16
HOL	1.23	0.63	0.55	0.85	0.93	3.16	2.45	3.50[b]	2.60	2.07	2.88[b]	2.01	2.92[b]	2.52	2.07
HUN	13.01**	8.69***	2.80	4.73[b]	4.43[b]	3.84[b]	3.29[b]	0.63	0.49	0.51	3.15[b]	3.87*	1.10	2.49	1.81
IRE	1.94	2.20	4.73[b]	5.73**	8.32**	7.12***	3.86[b]	2.75	1.87	3.25[b]	7.80***	5.14**	3.34[b]	2.08	1.90
ITA	6.50**	2.85	2.75	2.54	1.78	3.67[b]	5.38**	1.75	1.98	2.31	3.10[b]	4.82**	1.72	3.17[b]	3.36[b]
JAP	1.16	3.26	1.95	1.73	1.84	2.01	4.35**	2.65	1.10	1.79	1.54	2.85[b]	1.82	2.36	2.73[b]
KOR	24.53**	12.57***	19.36**	8.56**	3.97**	21.19***	8.41***	10.20**	7.06**	3.39[b]	15.58***	6.28**	9.75***	3.50[b]	1.95
MEX	1.09	0.67	0.13	0.49	0.66	1.67	1.50	2.36	1.49	1.52	1.67	1.53	3.48[b]	2.64	3.59[b]
NOR	2.20	1.60	1.51	1.89	2.53	3.54[b]	1.30	1.62	0.82	1.54	3.22[b]	1.86	2.77[b]	2.42	1.41
NZL	2.70	2.50	1.11	2.22	2.23	2.52	2.41	2.68	2.21	3.20[b]	3.12[b]	1.72	1.63	1.80	1.96
POL	5.23**	3.26	1.72	1.54	1.46	2.38	0.82	0.50	0.03	0.06	1.93	1.59	1.06	0.42	0.46
POR	0.04	0.13	0.11	0.06	0.06	6.68***	3.69[b]	2.50	2.82	3.73[b]	6.95***	3.75[b]	2.25	3.01[b]	4.59**
SPA	0.14	0.09	0.02	0.02	0.12	3.24[b]	1.19	1.62	1.00	1.20	2.25	1.06	1.17	0.91	1.27
SWE	4.41[b]	3.58	2.83	4.43[b]	3.60	1.48	0.74	0.89	0.83	1.23	2.12	2.46	2.55	3.26[b]	2.45
SWI	1.44	0.89	2.76	4.60[b]	6.42**	5.83**	8.05***	3.82[b]	3.37[b]	2.20	5.67***	7.02**	1.57	3.14[b]	1.67
TUR	0.64	1.16	2.65	2.31	1.65	7.51***	6.86***	3.28[b]	2.17	2.88	5.14**	4.62**	2.38	2.19	3.39[b]
UK	3.97	1.61	1.89	1.70	1.33	2.61	1.65	1.86	1.36	0.83	2.16	1.43	1.70	1.22	0.70
USA	0.53	0.90	1.71	1.74	3.10	1.14	1.11	0.78	0.96	1.17	1.98	1.26	0.54	0.71	0.47
USS	4.53[b]	2.21	3.27	2.33	1.06	4.57*	1.38	2.83	1.76	0.54	3.29[b]	0.92	2.58	2.04	1.76
BRA	3.75	3.48	2.18	3.63	0.81	2.50	1.93	1.61	1.46	1.57	2.65	1.83	1.70	1.65	1.25
CHN	6.70***	3.88	4.67[b]	7.22**	5.25*	2.64	2.99	2.49	3.46[b]	3.51[b]	3.63[b]	4.39**	2.86[b]	2.78[b]	3.80*
IND	0.10	0.58	2.59	1.71	1.66	4.25*	3.82*	1.16	1.14	0.75	2.50	2.39	0.59	0.86	0.37

[1] 1% CV (6.84;7.84), 5% CV (4.98;5.73) and 10% CV (4.04;4.78)

[2] 1% CV (5.15;6.36), 5% CV (3.79;4.85) and 10% CV (3.17;4.41)

[3] 1% CV (4.29;5.61), 5% CV (4.35;3.23) and 10% CV (3.77;2.72)

***, **,* significant at 1%, 5% and 10% respectively

[b] inconclusive at 1%

From the analysis above, when BT does not reject the existence of a long run relationship equation (3) is estimated. Therefore, the preferred functional form for each country is determined. Table A1 of Annex A summarizes the ECT estimation of equation (3) for each one of the possible functional forms. The results indicate the existence of a long run relationship between CO_2 emissions and economic activity, both in per capita terms, in a cubic path for Sweden, quadratic for Australia, Austria, Belgium, Canada, Denmark, Finland, The Netherlands, Ireland, Italy, Japan, Norway, Switzerland, China and India, and lineal for South Korea, Greece and Brazil. Finally, there is no long run relationship between the variables involved for any functional form for former Czechoslovakia, Hungary and the former Soviet Union. From the 17 countries for which a quadratic specification is possible, 14 present the turning point within the sample, which confirms an inverted-U path. The other 3 are very close to achieving it. Sweden also presents the turning points within the values of the sample.

The functional form specification for 18 countries of the sample has been determined, and the ECM for each one of them has been estimated. Moreover, for those countries that BT did not indicate the existence of a cointegration relation (France, United Kingdom, USA and Brazil), and for those that BT did not reject it for one of the specifications but was not possible to estimate a satisfactory long run relationship (Germany, Mexico, New Zealand, Poland, Portugal, Spain and Turkey), a unit roots analysis through the ADF statistic and a cointegration analysis through the Engle-Granger test are implemented. All the series for all the countries are I(1), and the existence of a long run relationship is not rejected for any of the specifications for France and Spain, the linear and quadratic specifications for Germany, Mexico, USA and Brazil, the cubic for Poland and the linear for Portugal and Turkey. The analysis rejects the existence of a long run relationship for New Zealand[11].

There is a long run quadratic relationship for France, Germany and USA, and linear for Mexico, Portugal, Spain, Turkey and Brazil. Poland and United Kingdom do not present any satisfactory specification, as equation (3) shows estimations for the specifications that do not reject the existence of a cointegration relationship.

Table II summarizes the results, 25 of the 31 countries of the sample do not reject the existence of a long run relationship between economic activity and CO_2 emissions (7 linear, 17 quadratic and 1 cubic). The result obtained confirms the heterogeneity among countries of behavior patterns for similar activity levels.

Comparing these results with other analyses for the same pollutant for individual countries, they are consistent with the ones of Iwata et al. (2009) for France (for the period 1960–2003), and Iwata et al. (2010) for Finland (1977–2003) and Japan (1966–2003). The last one tests —and obtains positive evidence of— the existence of a quadratic path for South Korea (1977–2003) and Spain (1968–2003), in contrast with the linear model supported by our results. Both works quoted take into account the share of nuclear power in total

[11] The results from the unit roots and cointegration tests are available from the authors upon request.

energy generation for each country. However, the linear specification for Spain is consistent with Roca and Padilla (2003) for the period 1980–2000, who also included factors referred to the energy sources structure.

Table II - Summary of long term relationship estimation		
Model	**Country**	**Decision Method**
Linear	BRA	EG
	GRE	BT
	KOR	BT
	MEX	EG
	POR	EG
	SPA	EG
	TUR	EG
Quadratic	AUS	BT
	AUT	BT
	BEL	BT
	CAN	BT
	CHN	BT
	DEN	BT
	FIN	BT
	FRA	EG
	GER	EG
	HOL	BT
	IND	BT
	IRE	BT
	ITA	BT
	JAP	BT
	NOR	BT
	SWI	BT
	USA	EG
Cubic	SWE	BT
No relation	CZE	BT
	HUN	BT
	NZL	EG
	POL	EG
	UK	EG
	USS	BT

In contrast with our results, Friedl and Getzner (2003) found a cubic relationship for Austria (1960–1999), introducing the weight of imports and industry in total income. Haciloglu (2008) also found a different path from ours for Turkey

(1960–2005), specifying a cubic functional form introducing the consumption of commercial energy and open grade, contrary to the linear one estimated here. However, analyzing the adjustment of Haciloglu's model, it seems that it approaches a linear relation through a cubic path but with a tiny decreasing section. Egli (2004) specifies a linear functional form for Germany (1966–1999), including industry participation in product and open grade, in contrast with the quadratic form specified by us. The difference in the results may be mainly due to the longer time period considered in our work, and to the fact that some of the above mentioned works include other independent variables that might be conditioning the functional form.

4.2. Homogeneity of the parameters and the turning point

The homogeneity of the parameters analysis is done constructing CI for the coefficients of the long run relationship, allowing different short run adjustments among countries, as well as for the intercept. The ECT multiplier homogeneity is also tested, in order to test the homogeneity in the speed of adjustment to deviations with respect to the long run relationship. Finally, the turning point homogeneity is tested for those countries presenting one.

Table A2 of Annex A presents the 95% CI[12]. Homogeneity of the parameters for models with linear and quadratic functional form is carried out separately. The homogeneity of the ECT parameter analysis can be done jointly for all the countries. CI overlaps are depicted in Figures 1 to 4.

[12] The results are similar construction 90% and 99% CI.

For those countries that follow a linear functional form, the long run relation parameter homogeneity is rejected for any group with more than 2 members at 95% confidence (3 at 99%) (Figure 1). For those that the quadratic path fits better, parameter homogeneity of the long run relation is rejected for any possible group with more than 4 countries at 95% CI (5 at 99%) (Figure 2a and Figure 2b)[13]. This result is consistent with the ones of Dijkgraff and Vollebergh (2001).

When the ECT adjustment parameter homogeneity among countries is studied, it is rejected for any group of countries with more than 8 countries at 95% confidence (10 at 99%) (Figure 3).

In summary, homogeneity is rejected for both, the functional form among countries and the parameters in the long run relation of the countries with same functional form. In no cases have we found any group of countries with more than five members with homogeneous parameters.

In spite of this, it is interesting to study the turning point homogeneity, since it could be that some countries achieved it for the same economic activity level despite presenting heterogeneous parameters in the long run relationship.

[13] Switzerland was excluded from the figure because it presents atypical values.

Figure 1: CI 95% - Linear Model

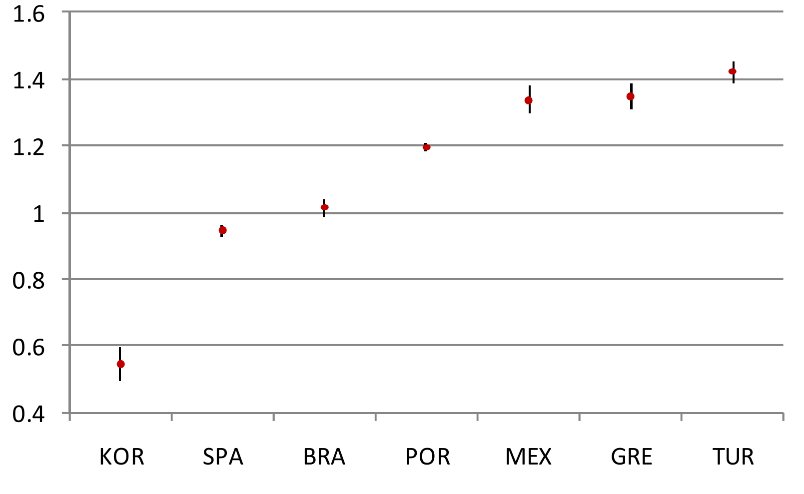


Figure 2a: CI 95%- Quadratic Model (β_1)

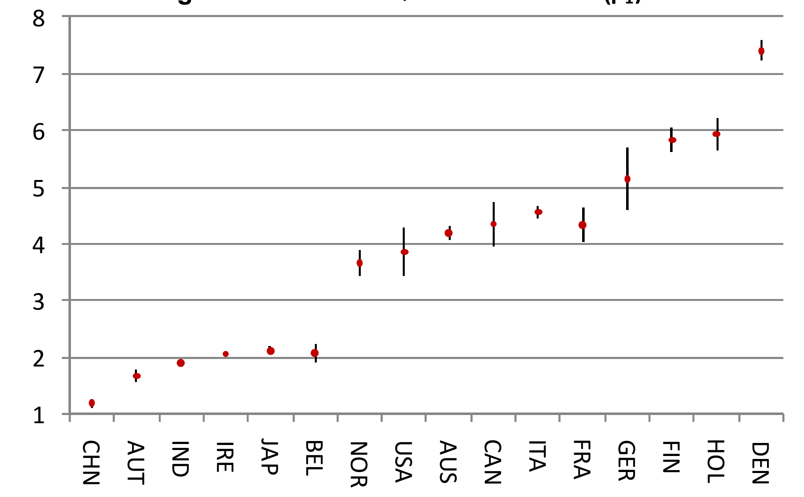
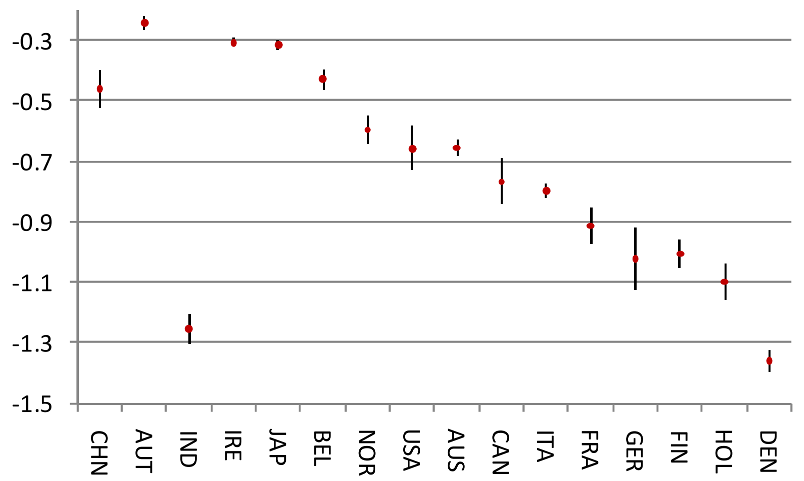


Figure 2b: CI 95% - Quadratic Model (β_2)



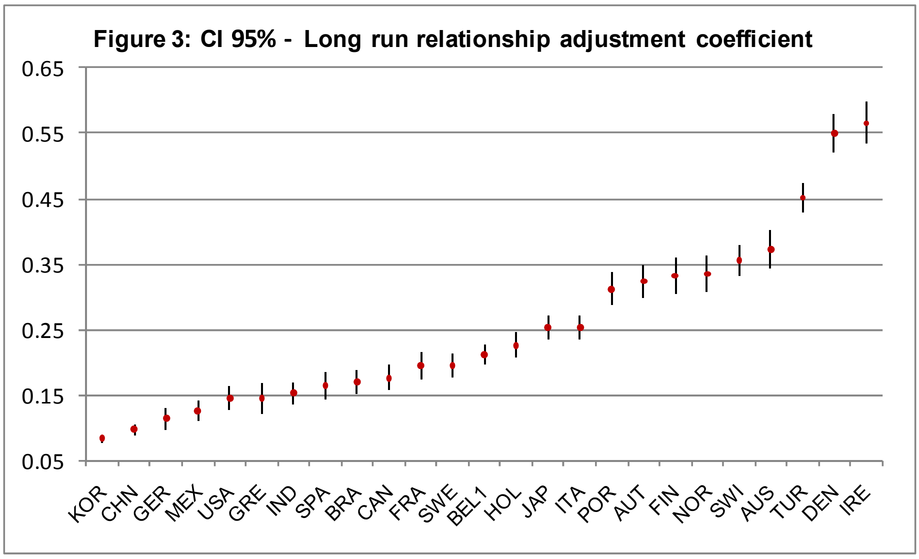


Figure 3: CI 95% - Long run relationship adjustment coefficient

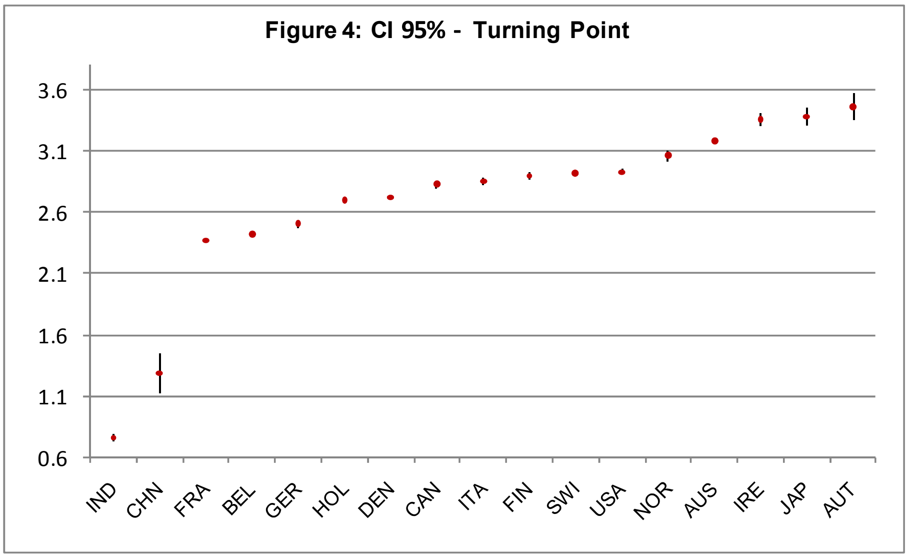


Figure 4: CI 95% - Turning Point

The turning point homogeneity for those countries with quadratic functional form is tested. Figure 4 shows that turning point homogeneity is clearly rejected for all the countries, and there are no groups with more than 4 countries at 95% confidence (5 at 99%).

It must be highlighted that, despite the rejection of turning point homogeneity for the whole sample of countries, there are some countries for which this hypothesis is not rejected, even though long run relation parameter was.

Denmark and The Netherlands is one example. These countries rejected the long run relation parameters homogeneity hypothesis, but present statistically homogeneous turning points. This implies that, for some countries it may occur that, despite they have divergent paths in the relationship between CO_2 emissions and economic activity, they achieve the turning point at the same threshold. If it were possible to generalize this result to the all countries, this would mean that policies must focus on avoiding high environmental non reversible damages. Other cases are Ireland, Japan and Austria, and Canada, USA, Finland, Italy and Switzerland.

Therefore, the questions to beg here are first, what are the factors explaining paths homogeneity for some countries, and second, what are the determinants that make countries with heterogeneous paths achieve the maximum level of emissions for the same activity level.

5. Conclusions

The present paper supports the existence of a long run relationship between CO_2 emissions and GDP per capita for 25 of the 31 countries for the period 1950–2006. However, the functional specification of these relationships is not homogeneous, being 7 linear, 17 quadratic and one cubic. Moreover, the parameters of the long run relationship homogeneity among countries are rejected, independently of the functional form. Finally, the turning point homogeneity for countries with quadratic functional form is also rejected.

Nonetheless, it might be noted that there are cases in which countries with non homogeneous paths achieve the turning point for a similar GDP per capita level.

The contribution of the present paper is three fold. First, it reinforces that we must be cautious about studies that carry out the estimations of the relation between CO_2 emissions and economic activity without considering that the series are non stationary (Grossman and Krueger, 1991 and 1994; Shafik and Bandyopadhyay, 1992; Carson et al. 1997; Cole et al. 1997; Vincent, 1997; de Bruyn et al., 1998 and Hung and Shawn, 2004). We reject the existence of a long run relationship between CO_2 emissions and economic activity level for some countries (former Czechoslovakia, Hungary, New Zealand, Poland, United Kingdom and former Soviet Union). Not considering this problem, above quoted works might include countries for which the relation is a spurious one.

Moreover, the functional form and parameters homogeneity among countries (or regions) assumptions are rejected. This is not tested in most studies (Grossman and Krueger, 1991 and 1994; Shafik and Bandyopadhyay, 1992; Selden and Song, 1994; Carson et al. 1997; Cole et al. 1997 and Vincent, 1997; Hung and Shawn, 2004 and Song et al., 2008). Therefore, panel data of countries (or regions) works that do not test homogeneity should be taken with a grain of salt, because assuming this restriction may lead to consider countries with the same GDP per capita level but different paths in homogenous way, or to erroneously assume that they will reach the turning point for the same GDP per capita level. In this way, we support the argument stated by de Bruyn et al. (1998) stipulating that in order to distinguish possible benefits stemming from economic activity growth in environmental quality, the study should focus on the analysis of the relationship between these factors at single country level.

The results of the present research are consistent with Dijkgraaf and Vollebergh (2001) and Dijkgraaf et al. (2005) on the problematic assumption of parameters homogeneity of the long run relation between CO_2 emissions and economic activity level, both per capita, employing a longer period sample, which allows a greater degree of overlapping of the series among countries. At the same time, this greater overlapping reinforces the result of rejecting the homogeneity in the functional form among countries (Perman and Stern, 1999 and 2003; List and Gallet, 1999; Dijkgraaf and Vollebergh, 2001; Martínez-Zarzoso and Bengochea-Morancho, 2003 and 2004 and Dijkgraaf et al., 2005). This is highlighted by the fact that heterogeneous functional forms are found for countries with similar level of economic activity.

The existence of a general relation for all the countries between CO_2 emissions and GDP per capita is clearly put into question. Following Carson (2010), this result rejects the optimistic view of the EKC, where developing countries might ignore environmental problems until they become developed. Developed countries can and have to consider this problem, since nothing guarantees a path as the one of the EKC for all countries (and neither the existence of a common path for them) (Dasgupta et al., 2002).

Finally, the turning point homogeneity is rejected for the whole sample of countries. However, there are groups of countries that present parameter heterogeneous paths but for which turning points homogeneity is not rejected. Although this is not strong evidence in favor of the optimistic view of the EKC, it suggests that it would be interesting to analyze the determinants of these countries. Moreover, the importance of considering the environmental degradation level from which the damage turns extremely high or irreversible must be highlighted, as while different countries might present a turning point for a similar level of activity, the environmental degradation achieved in this point might be different.

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Annex A

Table A1 - Error Correction Term - ECM cubic, quadratic and linear model

	AUS			AUT			BEL			CAN			CZE			DEN		
	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear
ADRL	(0,0,0,0)	(0,0,0)	(1,1)	(0,2,2,2)	(0,0,0)	(0,0)	(0,0,0,0)	(0,0,0)	(0,0)	(0,0,0,0)	(0,0,0)	(0,3)	(1,0,0,0)	(0,0,0)	(1,1)	(0,0,0,0)	(0,0,0)	(0,1)
alfa	-0.45	-0.37	-0.07	-0.30	-0.32	-0.04	-0.19	-0.21	-0.13	-0.16	-0.18	-0.09	0.01	-0.02	0.01	-0.53	-0.55	-0.11
t-statistic	*-3.47*	*-3.38*	*-1.92*	*-2.73*	*-3.32*	*-1.29*	*-2.59*	*-3.52*	*-1.89*	*-2.10*	*-2.30*	*-1.73*	*0.27*	*-0.79*	*0.42*	*-4.52*	*-4.96*	*-1.84*
C	-9.40	-3.13	-9.43	-9.89	-6.08	0.37	-6.48	-6.75	-9.19	21.29	-3.60	-8.52	11.21	-8.60	0.01	5.14	0.69	-8.48
t-statistic	*-1.95*	*-5.01*	*2.04*	*-3.11*	*-14.14*	*1.31*	*-6.04*	*-9.22*	*-39.02*	*0.99*	*-1.92*	*-19.24*	*2.99*	*-0.88*	*0.00*	*0.63*	*0.81*	*-9.23*
GDPPC(-1)	3.26	-4.18	0.00	1.84	-1.68	0.00	-2.59	-2.08	-0.06	-33.57	-4.35	-0.32	-7.11	-5.03	-5.60	-12.75	-7.40	-0.19
t-statistic	*0.57*	*-8.43*	*0.08*	*0.45*	*-4.37*	*0.00*	*-1.82*	*-3.49*	*-0.65*	*-1.34*	*-2.91*	*-1.90*	*-1.11*	*-0.59*	*-0.47*	*-1.29*	*-10.84*	*-0.55*
GDPPC^2(-1)	-2.25	0.66		-0.72	0.24		0.72	0.43		12.07	0.77		5.81	2.26		3.47	1.36	
t-statistic	*-1.01*	*6.77*		*-0.41*	*2.88*		*1.01*	*3.40*		*1.26*	*2.64*		*1.63*	*0.90*		*0.89*	*10.18*	
GDPPC^3(-1)	0.37			0.07			-0.05			-1.44			-1.34			-0.27		
t-statistic	*1.31*			*0.27*			*-0.43*			*-1.19*			*-2.07*			*-0.54*		
Interventions																		
Step															1970			
Impulse																		
Turning Point	3.07	3.19		5.36	3.46		2.39	2.42		2.61	2.83		0.88	1.11		2.70	2.72	
	0.95			1.68			7.15			2.97			2.01			5.75		
Schwartz iC	-3.84	-4.03	-3.86	-2.68	-3.10	-3.86	-3.14	-3.21	-2.97	-3.43	-3.46	-3.49	-3.51	-3.81	-3.71	-2.15	-2.21	-1.86
JB	1.08	0.83	0.58	0.45	0.75	0.75	0.10	0.32	0.72	2.07	1.97	4.72	4.78	5.44	7.56	1.16	0.85	1.13
p-value	*0.58*	*0.66*	*0.75*	*0.80*	*0.69*	*0.69*	*0.95*	*0.85*	*0.70*	*0.36*	*0.37*	*0.09*	*0.09*	*0.07*	*0.02*	*0.56*	*0.66*	*0.57*
BG (4 lags)	0.03	0.18	0.18	1.82	2.02	2.08	1.08	0.76	0.38	0.34	0.90	1.07	0.89	2.07	1.95	2.44	2.09	2.34
p-value	*1.00*	*0.95*	*0.95*	*0.14*	*0.11*	*0.10*	*0.38*	*0.56*	*0.82*	*0.85*	*0.47*	*0.39*	*0.48*	*0.10*	*0.12*	*0.06*	*0.10*	*0.07*
TP in the sample		YES			NO			YES			YES			YES			YES	

	FIN			FRA			GER			GRE			HOL			HUN		
	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear
ADRL	(0,0,0,0)	(0,0,0)	(0,0)	(0,0,0,0)	(0,0,0)	(0,0)	(0,0,0,0)	(0,0,0)	(0,0)	(0,0,0,0)	(0,0,0)	(0,0)	(0,0,0,0)	(0,0,0)	(0,0)	(0,0,0,0)	(0,0,0)	(3,3)
alfa	-0.33	-0.33	-0.09	-0.31	-0.20	-0.06	-0.26	-0.11	-0.04	-0.26	-0.19	-0.14	-0.20	-0.23	-0.02	-0.16	-0.11	0.01
t-statistic	*-3.02*	*-3.02*	*-1.68*	*-2.71*	*-2.47*	*-1.60*	*-2.49*	*-1.75*	*-1.16*	*-2.44*	*-2.41*	*-1.68*	*-2.43*	*-3.10*	*-0.48*	*-2.10*	*-1.90*	*0.26*
C	2.92	-0.90	-7.44	4.10	-3.90	-7.46	-1.64	-2.88	-9.80	-5.28	-4.69	-5.78	-20.04	-1.36	-10.55	21.29	-8.24	6.09
t-statistic	*0.60*	*-0.93*	*-6.48*	*0.72*	*-2.92*	*-7.07*	*-0.20*	*-1.01*	*-7.94*	*-6.94*	*-12.62*	*-15.05*	*-1.86*	*-1.05*	*-1.59*	*0.99*	*-3.43*	*0.12*
GDPPC(-1)	-11.44	-5.84	-0.64	-13.61	-4.34	-0.26	-6.55	-5.14	0.36	-1.73	-2.72	-1.35	14.98	-5.94	0.54	-33.57	-1.10	-9.03
t-statistic	*-1.70*	*-6.94*	*-1.44*	*-1.73*	*-3.81*	*-0.86*	*-0.67*	*-2.44*	*0.67*	*-1.05*	*-4.68*	*-9.18*	*1.16*	*-5.48*	*0.21*	*-1.34*	*-0.42*	*-0.28*
GDPPC^2(-1)	3.65	1.01		4.64	0.91		1.37	1.03		-0.14	0.39		-6.40	1.10		12.07	0.44	
t-statistic	*1.21*	*5.57*		*1.32*	*3.86*		*0.35*	*2.60*		*-0.14*	*2.13*		*-1.26*	*4.96*		*1.26*	*0.60*	
GDPPC^3(-1)	-0.40			-0.53			0.00			0.09			0.87			-1.44		
t-statistic	*-0.92*			*-1.05*			*0.00*			*0.49*			*1.32*			*-1.19*		
Interventions																		
Step														1982	1982			
Impulse																	1956	
Turning Point	imag.	2.90		imag.	2.37		2.40	2.51		3.11	3.45		3.00	2.70		2.61	1.26	
	imag.			imag.			1147.68			-2.08			1.92			2.97		
Schwartz iC	-1.61	-1.67	-1.59	-1.57	-2.83	-3.02	-3.80	-3.85	-3.91	-2.82	-2.92	-2.81	-2.82	-3.09	-2.77	-3.43	-2.98	-2.84
JB	2.01	1.25	1.13	3.36	1.56	0.34	1.47	0.26	0.48	0.48	1.91	0.45	4.96	7.87	9.06	2.07	7.00	0.26
p-value	*0.37*	*0.53*	*0.57*	*0.19*	*0.46*	*0.84*	*0.48*	*0.88*	*0.79*	*0.78*	*0.39*	*0.80*	*0.08*	*0.02*	*0.01*	*0.36*	*0.03*	*0.88*
BG (4 lags)	0.29	0.07	2.34	2.11	0.49	2.37	1.46	1.26	1.37	1.09	2.19	0.36	1.22	0.87	0.88	0.34	2.59	0.28
p-value	*0.88*	*0.99*	*0.07*	*0.09*	*0.74*	*0.07*	*0.23*	*0.30*	*0.26*	*0.37*	*0.08*	*0.84*	*0.32*	*0.49*	*0.48*	*0.85*	*0.05*	*0.89*
TP in the sample		YES			YES			YES			NO			YES			YES	

Table A1 - Error Correction Term - ECM cubic, quadratic and linear model

	IRE			ITA			JAP			KOR			MEX			NOR		
	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear
ADRL	(0,1,1,0)	(0,0,0)	(3,2)	(0,0,0,0)	(1,0,0)	(0,0)	(4,3,3,3)	(0,1,0)	(1,1,0)	(3,3,0,0)	(0,0,0)	(2,2)	(2,1,1,1)	(2,0,0)	(2,0)	(0,2,2,2)	(0,0,0)	(0,1)
alfa	-0.70	-0.57	-0.04	-0.15	-0.25	-0.04	-0.37	-0.25	-0.09	0.02	-0.10	-0.08	-0.24	-0.17	-0.12	-0.48	-0.34	-0.11
t-statistic	*-5.56*	*-4.58*	*-0.50*	*-1.96*	*-3.68*	*-1.32*	*-4.33*	*-3.64*	*-2.48*	*0.32*	*-2.54*	*-3.59*	*-3.30*	*-2.83*	*-2.14*	*-4.34*	*-3.19*	*-1.64*
C	-2.84	-5.94	-11.10	0.00	-2.45	-8.63	-6.96	-5.61	-5.58	7.50	-7.18	-7.44	-12.31	-3.87	-5.80	3.11	-3.49	-7.32
t-statistic	*-3.51*	*-28.65*	*-1.52*	*0.00*	*-5.51*	*-3.29*	*-7.82*	*-24.90*	*-10.14*	*0.19*	*-11.31*	*-17.48*	*-4.73*	*-3.28*	*-20.82*	*0.51*	*-3.14*	*-11.98*
GDPPC(-1)	-6.52	-2.06	1.44	-9.33	-4.56	-0.04	-1.21	-2.12	-1.13	-23.64	-1.45	-0.54	13.45	-4.34	-1.34	-12.86	-3.65	-0.66
t-statistic	*-5.52*	*-10.62*	*0.34*	*-1.43*	*-11.70*	*-0.04*	*-0.87*	*-8.50*	*-7.29*	*-0.38*	*-3.16*	*-2.80*	*2.35*	*-2.51*	*-8.18*	*-1.82*	*-4.03*	*-3.09*
GDPPC^2(-1)	2.29	0.31		3.30	0.80		0.20	0.31		13.01	0.24		-11.06	1.05		4.78	0.60	
t-statistic	*4.18*	*6.79*		*1.04*	*9.10*		*0.29*	*4.91*		*0.37*	*1.93*		*-2.72*	*1.77*		*1.76*	*3.32*	
GDPPC^3(-1)	-0.27			-0.40			-0.02			-2.48			2.67			-0.62		
t-statistic	*-3.35*			*-0.81*			*-0.14*			*-0.36*			*2.84*			*-1.80*		
Interventions																		
Step																		
Impulse																		2006
Turning Point	imag.	3.36		imag.	2.85		imag.	3.38		imag.	3.05		1.85	2.07		imag.	3.06	
	imag.			imag.			imag.			imag.			0.91			imag.		
Schwartz iC	-2.44	-2.36	-2.15	-3.52	-3.65	-3.66	-3.10	-3.12	-3.59	-2.75	-2.59	-3.16	-2.83	-2.89	-2.98	-1.62	-1.72	-1.69
JB	1.95	4.18	0.18	2.72	1.37	2.05	0.74	0.39	7.21	0.13	1.94	1.09	5.53	6.38	4.27	0.95	7.80	0.59
p-value	*0.38*	*0.12*	*0.92*	*0.26*	*0.50*	*0.36*	*0.69*	*0.82*	*0.03*	*0.94*	*0.38*	*0.58*	*0.06*	*0.04*	*0.12*	*0.62*	*0.02*	*0.75*
BG (4 lags)	0.85	0.76	1.63	0.60	0.53	0.63	3.11	2.32	1.88	1.31	0.89	0.53	1.79	0.49	1.21	0.88	2.69	2.30
p-value	*0.50*	*0.56*	*0.19*	*0.67*	*0.71*	*0.64*	*0.03*	*0.07*	*0.13*	*0.28*	*0.48*	*0.71*	*0.15*	*0.74*	*0.32*	*0.48*	*0.04*	*0.07*
TP in the sample		NO			YES			YES			NO			NO			YES	

	NZL			POL			POR			SPA			SWE			SWI		
	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear
ADRL	(0,0,0,0)	(0,0,0)	(0,0)	(0,0,0,0)	(0,0,0)	(0,0)	(0,0,0,0)	(0,0,0)	(1,0)	(0,0,0,0)	(0,0,0)	(0,0)	(0,0,0,0)	(0,0)	(0,0)	(1,1,1,1)	(0,0,0)	(0,1)
alfa	-0.34	-0.26	-0.25	0.03	0.03	0.00	-0.57	-0.55	-0.31	-0.29	-0.31	-0.16	-0.20	-0.14	-0.06	-0.38	-0.36	-0.04
t-statistic	*-3.40*	*-2.66*	*-2.80*	*0.78*	*0.66*	*0.03*	*-3.82*	*-3.79*	*-3.21*	*-3.48*	*-3.93*	*-2.15*	*-2.62*	*-2.00*	*-1.57*	*-2.51*	*-3.80*	*-0.74*
C	-64.77	-7.07	-6.50	-2.18	-0.31	93.13	-5.58	-5.82	-5.58	-5.54	-5.94	-6.42	44.63	-0.58	-11.72	41.20	14.38	-8.87
t-statistic	*-2.64*	*-2.20*	*-20.50*	*-0.44*	*-0.04*	*0.02*	*-14.23*	*-46.03*	*-61.00*	*-6.34*	*-26.10*	*-34.58*	*2.00*	*-0.14*	*-4.90*	*0.85*	*5.29*	*-1.72*
GDPPC(-1)	70.12	-0.43	-0.87	-6.77	-8.76	-66.08	-1.37	-0.90	-1.20	-2.39	-1.63	-0.95	-61.52	-7.17	1.07	-42.33	-15.80	0.17
t-statistic	*2.33*	*-0.16*	*-6.91*	*-1.41*	*-1.14*	*-0.03*	*-1.77*	*-5.18*	*-30.44*	*-1.48*	*-6.08*	*-12.61*	*-2.26*	*-2.30*	*1.18*	*-0.81*	*-8.00*	*0.09*
GDPPC^2(-1)	-28.66	-0.09	0.39	1.63	2.19		0.21	-0.08		0.61	0.19		23.04	1.50		11.32	2.70	
t-statistic	*-2.34*	*-0.17*	*1.82*	*1.23*	*1.14*		*0.45*	*-1.65*		*0.69*	*2.63*		*2.11*	*2.48*		*0.61*	*7.56*	
GDPPC^3(-1)	3.83			0.33			-0.06			-0.07			-2.82			-0.92		
t-statistic	*2.32*			*0.60*			*-0.64*			*-0.48*			*-1.96*			*-0.42*		
Interventions																		
Step					1981, 1990	1981, 1990												
Impulse																		
Turning Point	2.83	-2.44		1.44	2.00		imag.			imag.	4.27		2.33	2.39		2.87	2.92	
	2.16			-4.72			imag.			imag.			3.12			5.36		
Schwartz iC	-2.83	-2.81	-2.87	-3.72	-3.80	-3.47	-2.66	-2.72	-2.84	-2.74	-2.81	-2.80	-2.23	-2.23	-2.26	-2.61	-2.74	-2.45
JB	3.94	1.55	0.95	4.60	3.76	1.54	1.30	1.67	0.43	2.40	2.22	0.41	0.72	1.01	0.69	0.64	0.67	0.64
p-value	*0.14*	*0.46*	*0.62*	*0.10*	*0.15*	*0.46*	*0.52*	*0.43*	*0.81*	*0.30*	*0.33*	*0.81*	*0.70*	*0.60*	*0.71*	*0.73*	*0.72*	*0.73*
BG (4 lags)	1.08	0.50	1.04	1.80	1.99	2.17	1.38	1.22	0.49	1.76	1.86	1.01	0.93	0.86	0.82	1.55	3.28	2.26
p-value	*0.38*	*0.74*	*0.40*	*0.15*	*0.11*	*0.09*	*0.25*	*0.31*	*0.74*	*0.15*	*0.13*	*0.41*	*0.45*	*0.50*	*0.52*	*0.21*	*0.02*	*0.08*
TP in the sample		YES			YES			YES			NO			YES			YES	

Table A1 - Error Correction Term - ECM cubic, quadratic and linear model

	TUR			UK			USA			USS			BRA			CHN			IND		
	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear
ADRL	(0,0,0,0)	(0,0,0)	(0,0)	(0,0,0,0)	(0,0,0)	(0,0)	(0,0,0,0)	(0,0,0)	(0,0)	(1,2,2,2)	(1,0)	(1,0)	(0,0,0,0)	(4,4,0)	(0,0)	(1,1,0,0)	(1,1,1)	(1,1)	(0,0,0,0)	(0,0,0)	(0,0)
alfa	-0.24	-0.45	-0.16	-0.40	-0.22	-0.20	-0.17	-0.14	-0.05	0.03	-0.09	-0.06	-0.04	-0.07	-0.17	-0.16	-0.10	-0.06	-0.15	-0.15	0.01
t-statistic	*-1.51*	*-4.14*	*-1.79*	*-3.59*	*-2.18*	*-2.63*	*-2.37*	*-2.06*	*-1.47*	*0.43*	*-2.09*	*-1.56*	*-0.43*	*-0.77*	*-2.37*	*-4.13*	*-2.91*	*-2.45*	*-2.34*	*-2.38*	*0.24*
C	-5.14	-4.62	-5.52	-0.41	-9.47	-9.76	27.26	-4.31	-9.10	51.12	-7.45	-7.77	-9.85	-5.37	-5.70	-7.24	-6.94	-6.66	-6.57	-6.57	-0.13
t-statistic	*-4.80*	*-31.12*	*-26.46*	*-0.08*	*-7.67*	*-68.43*	*1.26*	*-1.94*	*-19.65*	*0.42*	*-4.35*	*-15.70*	*-0.71*	*-4.61*	*-35.68*	*-71.38*	*-41.36*	*-26.18*	*-55.43*	*-57.39*	*-0.01*
GDPPC(-1)	-1.92	-2.80	-1.42	-10.82	-0.01	0.24	-37.70	-3.85	-0.12	-127.59	-1.26	-0.85	9.15	-3.28	-1.02	-1.11	-1.19	-0.69	-1.90	-1.91	-2.29
t-statistic	*-0.65*	*-11.02*	*-11.40*	*-1.83*	*-0.01*	*3.95*	*-1.64*	*-2.42*	*-0.76*	*-0.48*	*-0.57*	*-2.86*	*0.26*	*-1.12*	*-9.67*	*-7.47*	*-4.23*	*-2.54*	*-15.05*	*-22.94*	*-0.64*
GDPPC^2(-1)	-0.17	0.51		4.27	0.05		12.65	0.66		89.47	0.12		-10.90	1.20		1.45	0.46		1.28	1.25	
t-statistic	*-0.07*	*5.15*		*1.81*	*0.24*		*1.56*	*2.33*		*0.47*	*0.17*		*-0.31*	*0.79*		*5.18*	*1.95*		*4.14*	*6.42*	
GDPPC^3(-1)	0.19			-0.55			-1.40			-20.65			3.75			-0.71			-0.06		
t-statistic	*0.30*			*-1.75*			*-1.49*		*1.039*	*-0.47*		*0.208*	*0.33*			*-3.91*			*-0.13*		
Interventions																					
Step									1970							1958	1958	1958			
Impulse																			1977	1977	1977
Turning Point	2.20	2.72		2.16	0.05		2.74	2.93		1.28	5.07		1.32	1.36		imag.	1.29		0.78	0.76	
	-1.58			3.06			3.26			1.60			0.62			imag.			13.18		
Schwartz iC	-2.44	-2.97	-2.79	-3.91	-4.03	-4.10	-3.91	-3.93	-4.69		-4.05	-4.15	-2.82	-2.88	-3.34	-2.40	-2.26	-2.33	-4.12	-4.19	-4.13
JB	1.32	0.21	0.63	0.02	0.35	0.43	0.68	1.30	1.73	4.12	0.74	0.43	0.46	0.75	1.31	3.41	7.79	3.57	2.44	2.29	1.42
p-value	*0.52*	*0.90*	*0.73*	*0.99*	*0.84*	*0.81*	*0.71*	*0.52*	*0.42*	*0.13*	*0.69*	*0.81*	*0.79*	*0.69*	*0.52*	*0.18*	*0.02*	*0.17*	*0.29*	*0.32*	*0.49*
BG (4 lags)	0.22	0.26	0.61	0.26	0.22	0.23	0.54	1.25	0.47	0.61	0.57	1.37	1.75	1.78	2.29	2.03	0.39	0.62	2.68	2.69	2.32
p-value	*0.93*	*0.90*	*0.66*	*0.90*	*0.93*	*0.92*	*0.71*	*0.30*	*0.75*	*0.66*	*0.69*	*0.26*	*0.16*	*0.15*	*0.07*	*0.11*	*0.82*	*0.65*	*0.04*	*0.04*	*0.07*
TP in the sample		NO			YES			YES			NO			YES			YES			YES	

Table A2 - Confidence Intervals (95% confidence): Long run relationship parameters, speed of adjustment and turning point

	Adjustment coeffiecient			Linear			Quadratic						TP		
	Ext. Inf	$\hat{\alpha}$	Ext. Sup	Ext. Inf	$\widehat{\text{coef gdppc}}$	Ext. Sup	Ext. Inf	$\widehat{\text{coef gdppc}}$	Ext. Sup	Ext. Inf	$\widehat{\text{coef gdppc2}}$	Ext. Sup	Ext. Inf	$\hat{\theta}$	Ext. Sup
BRA	-0.19	-0.17	-0.15	-1.04	-1.02	-0.99									
GRE	-0.17	-0.14	-0.12	-1.39	-1.35	-1.31									
KOR	-0.09	-0.08	-0.08	-0.59	-0.54	-0.49									
MEX	-0.14	-0.12	-0.11	-1.38	-1.34	-1.30									
POR	-0.34	-0.31	-0.29	-1.21	-1.20	-1.19									
SPA	-0.18	-0.16	-0.14	-0.96	-0.95	-0.93									
TUR	-0.47	-0.45	-0.43	-1.45	-1.42	-1.39									
AUS	-0.40	-0.37	-0.34				-4.31	-4.18	-4.06	0.63	0.66	0.68	3.16	3.19	3.21
AUT	-0.35	-0.32	-0.30				-1.78	-1.68	-1.58	0.22	0.24	0.26	3.35	3.46	3.57
BEL[1]	-0.23	-0.21	-0.20				-2.24	-2.08	-1.92	0.40	0.43	0.46	2.40	2.42	2.44
CAN	-0.20	-0.18	-0.16				-4.73	-4.35	-3.96	0.69	0.77	0.84	2.80	2.83	2.86
CHN	-0.11	-0.10	-0.09				-1.26	-1.19	-1.11	0.40	0.46	0.52	1.13	1.29	1.45
DEN	-0.58	-0.55	-0.52				-7.58	-7.40	-7.23	1.33	1.36	1.40	2.71	2.72	2.73
FIN	-0.36	-0.33	-0.30				-6.05	-5.84	-5.62	0.96	1.01	1.05	2.87	2.90	2.93
FRA	-0.22	-0.20	-0.17				-4.63	-4.34	-4.04	0.85	0.91	0.98	2.36	2.37	2.39
GER	-0.13	-0.11	-0.10				-5.69	-5.14	-4.60	0.92	1.03	1.13	2.48	2.51	2.54
HOL	-0.25	-0.23	-0.21				-6.22	-5.94	-5.66	1.04	1.10	1.16	2.69	2.70	2.72
IND	-0.17	-0.15	-0.14				-1.93	-1.91	-1.89	1.20	1.25	1.31	0.74	0.76	0.79
IRE	-0.60	-0.57	-0.53				-2.11	-2.06	-2.01	0.29	0.31	0.32	3.30	3.36	3.41
ITA	-0.27	-0.25	-0.24				-4.66	-4.56	-4.46	0.78	0.80	0.82	2.83	2.85	2.88
JAP	-0.27	-0.25	-0.23				-2.18	-2.12	-2.05	0.30	0.31	0.33	3.30	3.38	3.46
NOR	-0.36	-0.34	-0.31				-3.89	-3.65	-3.42	0.55	0.60	0.64	3.02	3.06	3.11
SWI	-0.38	-0.36	-0.33				-16.31	-15.80	-15.29	2.61	2.70	2.80	2.92	2.92	2.93
USA	-0.16	-0.14	-0.13				-4.27	-3.85	-3.44	0.58	0.66	0.73	2.91	2.93	2.95
SWE	-0.21	-0.20	-0.18												

[1] n=55 (1952 - 2006)

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