Could environmental policies be enforced without affecting economic growth?

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ABSTRACT

The aim of this paper is to determine whether constraining the release of CO2 emissions is neutral on economic growth in 81 countries for the period 1950–2008. We test for cointegration in the CO2-GDP relationship using non-linear methodology, rather than the linear methodology commonly used in the empirical literature. While there is scarce evidence of cointegration when using the linear approach; when a smooth transition autoregressive (STAR) is applied, the results are more favourable to the existence of a long-run relationship linking the variables.

KEYWORDS: CO_2 emissions, GDP, nonlinear cointegration.

1. INTRODUCTION

The highly complex relationship between economic growth and environmental degradation is an important issue faced by society in the interest of achieving sustainable development.

The fact that most economic activities require energy has been a cause of great concern, arising from the close link between both macro-variables. This is therefore a matter of vital importance, as in the event that there is a positive relationship between the two macro-variables, adopting policies and protocols to reduce current levels of emissions could severely compromise countries' economic development, especially that of the less developed countries.

Although nowadays emerging countries release a greater amount of CO2 into the atmosphere than industrialised nations, up until recently the latter released the greater amount, and are responsible for the environmental damage caused to date. Therefore, if energy acts as a limiting factor for economic growth, as claimed by emerging countries, it would be unfair to ask them to make a commitment towards reducing gas emissions, or at least not to the same extent as developed countries, as the former's future growth would be affected.

Accordingly, environmental policies have begun to be a matter of concern not only for scientists but also for economists, as efforts to prevent climate change may also reduce economic growth. This troubling trade-off between emission limitation and economic development has led to a wide variety of empirical studies that can be split into three main streams.

The first empirical studies are based on the concept of an Environmental Kuznets Curve (EKC) which posits that a country's economic development is positive for the environment since when a country reaches a certain critical level of development it can afford and will be willing to allocate resources to environmental protection.

Investing in actions such as conservation and energy efficiency, substituting fossil fuels with alternative energy such as nuclear or renewable, or creating forest carbon sinks are all mitigation measures to stabilise the concentration of greenhouse gas (GHG) emissions. They each allow the country’s GDP to increase while stabilising or even reducing emissions levels. Although a large number of studies aim to validate the EKC hypothesis, it remains empirically open.

A second strand of the literature focuses on studying - mostly using methodology proposed by Granger (1987) - if there is a significant causal relationship between energy consumption and emissions, analysing and interpreting the direction of relationship. It tests whether it is economic development that stimulates energy consumption, or vice versa, or even if there exists a bidirectional relationship between the two variables.

If it is proven that it is energy consumption which stimulates economic development, energy would therefore be a limiting factor in the country’s growth. In this case, we would be faced with economies dependent on energy for growth.

If the causality is unidirectional and runs from economic development to energy consumption, this would mean that environmental protection measures could be adopted without compromising growth.

The absence of a relationship between the two variables would mean that energy is a neutral input in economic development. Therefore, the growth trajectory would continue independently of energy consumption.

Finally, evidence in favour of a bidirectional relationship between energy consumption and growth would suggest that both are complementary. This should be taken into account when modelling the relationship as both variables would have to be considered endogenous.

Nevertheless, as proven by Chontanawat et al. (2006) and Hu and Lin (2008), the causal relationship in as per Granger between energetic consumption and growth is empirically ambiguous and controversial. A valuable work of synthesis is that created by Hung et al. (2008, Table 1) showing the discrepancies between the studies even for cases where the sample of countries is identical. This author argues that much of the heterogeneity in the results is due to the differing methodologies applied.

On the other hand, Zachiaridis (2007) points to the bivariate relationship as a trigger of the empirical discrepancy, since the effects of other variables may be masked under a bivariate relationship. However, as indicated by

Peguin-Feissolle, Strikholm and Teräsvirta (2007) the problem could be the functional linear form specified to link the two variables rather than the number of variables analysed. These authors point to the fact that the Granger linear causality test has a low power detecting certain non-linear causality. Péguin-Feissolle, Strikholm and Teräsvirta (2007) propose a statistical method for uncovering nonlinear causal relations that, by construction, cannot be detected by traditionally linear causality tests.

2. CONTRIBUTION

Despite it being possible, through the approach of Peguin-Feissolle, Strikholm and Teräsvirta (2007), to resort to a causality analysis such as that of Granger, taking into account possible non-linearities; results are obtained through this methodology which depend enormously on the definition of variables, the period of time selected, as well as the selection of delays, which makes it an inappropriate test for the study of the long-run relationship of the dynamic between energy consumption and economic growth.

Therefore, in this article, cointegration theory is applied to determine the existence of a long-term equilibrium between both variables. Specifically, we will attempt to discern if the CO2 emissions used as a proxy for energy consumption are a critical input for GDP growth, used as a representative measure of economic growth.

The aim thus is to assess whether CO2 emissions series and GDP share co-movements over time. Confirming this relationship would have important implications since it would result in the growth hypothesis suggesting that energy consumption contributes directly to economic growth and therefore, any policy implying a contraction in energy use will have negative effects on countries' economic development. The implication of these results would be even worse for developing countries, as issues such as the index of specialisation in highly polluting activities and inefficient and outdated technology mean that these countries release large amounts of emissions. Hence policy makers would face a worrying political trade-off: to not impose restrictions on the use of energy or to limit economic growth.

This article aims to contribute to the literature analysing the possible long-term relationship between CO2 and GDP series within a nonlinear framework. The reasons for considering non-linearities in the CO2-GDP ratio are several:

-Energy prices causing different CO2 regimes

Historical events suggest that after a significant and persistent increase in energy prices over time, a downward adjustment of the ratio of gross domestic product is usually produced. However, this adjustment is not instantaneous. A delay exists between the rise in prices and the fall of the level of production. This contraction of the economy causes, after a transitory period, a smaller level of emissions which will predictably be maintained until energy prices, especially oil prices, significantly vary again.

Energy prices are one of the potential channels of causality that, by means of the implementation of a multivariate model, would enrich the information on the relationship between CO2-GDP.

The high volatility of this variable means that linear models are an unsuitable framework for capturing the dynamic of the CO2-GDP relationship. Although we are evaluating a bivariate relationship, it is important to note that this nonlinear pattern of energy prices could be transferred to the CO2-GDP ratio as energy prices may be behind certain contractions and expansions experienced by the GDP and hence in emissions. The use of standard tests (linear) may cause transitions between regimes to be interpreted as features of a non-stationary process although the series in question is in fact nonlinear but globally stationary.

If the CO2-GDP ratio has nonlinear dynamics and non-simultaneous adjustment, neglecting these features would lead to the erroneous conclusion that the CO2-PIB combination produces an I (1) residue, meaning that there is no cointegration relationship between the two variables. Choosing a test that allows a gradual rather than instantaneous adjustment avoids the possible erroneous misinterpretation of the order of integration of the CO2-GDP relationship.

-Porter Hypothesis and Pollution Haven Hypothesis

More stringent environmental regulation increases competitive pressure, especially in those firms operating in the dirtiest activities. Although initially these companies try to buy emissions rights in order to continue releasing similar levels of CO2, in a certain period of time they will have to choose between several alternatives: to produce less, therefore limiting emissions; to invest in clean technologies to enable them to adapt to regulations; or to move to countries with lax environmental regulations. The latter alternative is known as the Pollution Haven Hypothesis (PHH), which states that companies in countries forced to comply with strict environmental regulations such as those belonging to the European Union and those that have ratified the Kyoto agreement, may eventually relocate to countries with weaker environmental laws[1].

According to PHH, the emissions of countries submitted to regulatory pressure may suffer a downturn as a consequence of tightening environmental regulations, creating a reduction in the amount of CO2 released. Nevertheless, it is unlikely that companies "migrate" suddenly in response to the new regulatory framework. Instead, one would expect there to be a gradual change in the deterministic structure of the relationship.

On the other hand, the second alternative listed is known as the Porter Hypothesis, which states that strict environmental regulation results in companies forced to comply with the regulations becoming more efficient and more innovative, increasing their competitiveness. Changes in production functions will be transferred to the emissions series which undergo structural changes in their deterministic components. It seems likely that these lower levels of emissions would lead to a new regime that will be reached progressively as the company invests in clean technologies and / or becomes more efficient.

- *Changes in sectoral specialisation*

  Changes in the deterministic structure of the GDP-CO2 relationship can also be explained by the different contributions of different sectors to GDP as a country grows. While in the early stages of industrialisation, sectors such as agriculture lose importance in favour of the manufacturing sector; in the more advanced stages of development manufacturing and other consumer goods sectors whose production releases large amounts of emissions are replaced by an economy whose main contributor to GDP is the services sector. This undoubtedly creates a structural change in the emissions series that the lack of flexibility in linear tests perhaps prevents them from being able to capture.

- *The environment as a luxury good*

  The Environmental Kuznets Curve (EKC) assumes that the structure of the series will be altered as the CO2 emissions reach a different regime to that of when the environment was considered as a normal good.

In short, the alterations that can be produced by the deterministic components of the CO2-GDP relationship as a consequence of economic shocks such as an increase in energy prices, sectoral changes in GDP, relocation of companies or even the consideration of the environment as a luxury good are varied and appear to be quite probable. All of these will cause different levels of the series, and therefore the initial intuition points to the existence of thresholds and to the transition between them will occur gradually.

Nevertheless, most studies analysing the CO2-GDP ratio are within a linear framework, which implies the assumption that all the changes discussed above occur instantaneously, i.e. that the agents react simultaneously to an economic shock. Additionally, linear tests assume that the process will revert to its above average value after the shock, therefore linear methods do not consider that the process can be in a different regime, and therefore have a different mean value, as a result of a change in its deterministic structure.

All of the above leads us to conclude that the most appropriate models to capture the possible relationship of cointegration between CO2 and GDP are those that allow for gradual changes in their deterministic structure in order to capture the different levels of the variables. While a priori it seems that models that allow changes to occur gradually are the best, in this article we develop a battery of both linear and non-linear tests, as linear tests should not be seen as conflicting, but rather complementary to those that take nonlinearities into account, allowing us to evaluate the average behaviour of the series.

3. EMPIRICAL STRATEGY AND DATA

We will study if a long-term relationship exists between CO2 emissions and GDP, and also test if both series are cointegrated. For this, data for 81 countries from the International Energy Agency (IEA) from 1960 to 2008 are used for annual CO2 emissions in metric tons, while the GDP is obtained from the World Bank database.

Since Engle and Granger (1987) first introduced the concept of cointegration, it has become a fundamental analysis and prerequisite for any type of evaluation between two (or more) non-stationary variables. Two (or more) non-stationary variables are cointegrated if a linear combination between them results in a stationary process. The fact that the difference between the two series is stable, i.e. stationary, implies that both move together over time, being in long-run equilibrium because they share a common stochastic trend.

Nevertheless, the Granger approach suffers a number of problems such as the need to specify the dependent and independent variables significantly varying the results depending on the specification. One of the most common alternatives to overcome these problems is proposed by Johansen (1991):

Consider a general model VAR (p):

Equation 1

$$Y_t = \mu + \Phi\, D_t + A_p Y_{t-p} + \ldots + A_1 Y_{t-1} + \varepsilon_t$$

where Y_t is a nx1 vector of variables integrated of order one, while ε_t is a nx1 of innovations. This VAR can be written in a vector error correction model (VECM) form as:

Equation 2

$$\Delta\, Y_t = \mu + \Phi\, D_t + \sum_{i=1}^{p-1} \Gamma_i\, \Delta Y_{t-i} + \ldots + \Pi_1 Y_{t-1} + \varepsilon_t$$

where $\Pi = \sum_{i=1}^{p-1} A_i - I$ y $\Gamma_i = -\sum_{j=i+1}^{p} A_j$

The existence of cointegration will be determined by the rank of the coefficient matrix Π. If the rows of Π are not linearly independent, then nxr matrices α and β exist, each with rank r such that $\Pi = \alpha\beta'$ and $\beta' Y_t$ is stationary. The number of cointegration relationships is given by r. The α elements are the adjustment parameters in the VECM while each column of β is a cointegrating vector.

Johansen (1991) suggests two different test statistics, the trace test and maximum eigenvalue test. In this paper the first is applied:

Equation 3

$$\lambda_{TRACE} = -T \sum_{i=r+1}^{n} \ln(1 - \hat{\lambda})$$

where T is the simple size and y $\hat{\lambda}_i$ is the largest canonical correlation.

The trace test assumes the following hypothesis:

$$H_0 = Exist\ r\ \ r\ cointegrating\ vectors$$

$$H_a = Exist\ n\ cointegrating\ vectors$$

Linear cointegration methodology, including that of Johansen (1991), supposes that deviations to the long-run equilibrium are symmetric, constant and occur in each period. This, however, is not necessarily true. The costs of adjustment or (discrete) policy interventions might invalidate the above-mentioned suppositions. Adjustment costs or (discrete) policy interventions could invalidate these assumptions.

In the event that there are nonlinearities due to multiple regimes, the linear cointegration captures at best an average behaviour of the regimes. It is possible that if the process has a local non-stationary behaviour, this would lead one to conclude that it has a unit root even if the process could be globally stationary.

Contrasts that allow adjustments to not only happen instantaneously but rather only when these deviations exceed a critical threshold can be used to detect the behaviour of the possible (local) regimes. The existence of such thresholds could be assessed by a SETAR (self-exciting threshold autoregressive) model, which is just a certain case of TAR model (threshold autoregressive). A TAR model is ideal to represent variables that, despite behaving in a linear way in a regime, are nonlinear in their path as a result of the different regimes they follow. The regime changes are driven by the threshold variable.

Equation 4

$$Y_t = \begin{cases} \emptyset_1 + \emptyset_{10} Y_t + \emptyset_{11} Y_{t-d} + \ldots + \emptyset_{1L} Y_{t-(L-1)d} + \epsilon_{t+s} & Z_t \leq Y_{t-\delta d}\,. \\ \emptyset_2 + \emptyset_{20} Y_t + \emptyset_{21} Y_{t-d} + \ldots + \emptyset_{2H} Y_{t-(H-1)d} + \epsilon_{t+s} & Z_t > Y_{t-\delta d}\,. \end{cases}$$

where Z_t is the threshold variable. The difference between the TAR and SETAR model is precisely the threshold variable. While in the former this may be any variable, in SETAR models the variable causing regime changes is the variable itself. That is, the variable threshold is $Y_t, Y_{t-d}, Y_{t-(m-1)d}$ and can be defined as:

Equation 5

$$Z_t = Y_{t-\delta d}\,.$$

Equation 1 can be written in a regression form as:

Equation 6

$$Y_t = I_L\big(\emptyset_1 + \emptyset_{10}Y_t + \emptyset_{11}Y_{t-d} + \ldots + \emptyset_{1L}Y_{t-(L-1)d}\big)$$
$$+ I_H\,(\emptyset_2 + \emptyset_{20}Y_t + \emptyset_{21}Y_{t-d} + \ldots + \emptyset_{2H}Y_{t-(H-1)d}$$
$$+ \epsilon_{t+s})$$

Where I_a are dummy functions that take either 0 or 1 depending on if $Y_{t-1} \in a$ where a = L, M or H:

$$I_a = \begin{cases} 1 \quad if\, Y_{t-1} \quad \epsilon \quad a \\ \quad 0 \quad else \end{cases}$$

The SETAR models will allow us to discern between a globally stationary process with local non-stationary behaviour, and therefore non-linear and a process with a unitary root, which the linear models are unable to do.

In fact, the key lies in how different models calculate the conditional average. While linear models estimate a single average for the process, the TAR models use piecewise modelling of the series, allowing a better approximation for models with deterministic changes such as the case of CO2-GDP ratio for the reasons given above.

There are piecewise linear models that allow for model changes to occur in the "time" space, however the TAR model uses threshold space to improve linear approximation. This means that for the TAR model the key variable to estimate the conditional mean will not be the time "t" but the value "x" variable CO2-GDP.

One criticism of the TAR models is that, while they allow for the existence of regimes, they consider that the changes between them take place suddenly. This implies that its conditional mean is not continuous as the threshold points are the discontinuous points. As well as this being unrealistic in many cases, the lack of continuity in the objective function I causes additional problems. To overcome this problem, Stigler (2009) proposes the concentration of the objective function. As, given a threshold, the estimates of $\emptyset$ in Equation 3 are OLS, the problem can be reduced to minimizing the sum of squared errors associated with the parameters, SSR (θ). Thus, the objective function is:

Equation 7

$$\hat{\theta} = \arg\min_{\theta} SSR\ (\theta)$$

Once the threshold is estimated it can be added to the SETAR model, checking whether it is significant and, if so, implementing the most appropriate methodology.

If the existence of thresholds has been validated, the following step would be to address the relationship between the variables using cointegration methodology that takes into account the existence of thresholds in the relationship.

Balke and Fomby (1997) are the first authors to indicate how the linear cointegration approach assumes that adjustments of the deviations to the long-run equilibrium are made instantly and in each period rather than when a certain threshold is exceeded. To circumvent this linear drawback

Balke and Fomby (1997) suggested an alternative specification to the linear adjustment process:

Equation 8

$$\varepsilon_t = \rho\varepsilon_{t-1} + u_t$$

which is replaced for:

Equation 9

$$\varepsilon_t \begin{cases} \rho_L \varepsilon_{t-1} + u_t & if & \varepsilon_{t-1} \leq \theta_L \\ \rho_M \varepsilon_{t-1} + u_t & if & \theta_L \leq \varepsilon_{t-1} \leq \theta_H \\ \rho_H \varepsilon_{t-1} + u_t & if & \theta_H \leq \varepsilon_{t-1} \end{cases}$$

where L, M y H indicate the low, medium and high and are differentiated by the threshold value θ. This proposal allows the major criticism of linear cointegration methodology to be overcome.

Threshold cointegration is actually a linear model where three AR (1) models are estimated piecewise depending on the value of the threshold variable in t-1. While the work of Balke and Fomby (1997) focuses on long-term representation, other authors such as Seo (2006) have extended the concept to the vector error correction TVECM threshold, thereby avoiding loss of short term information.

Many contrasts specify no cointegration as a null hypothesis. However, to the best of our knowledge, Seo (2006) is the only test with threshold as an alternative hypothesis based on vector error correction.

Seo (2006) suggests a threshold vector error correction model with the error correction (ECT) divided into three regimes, where the endogenous variable is not adjusted in the middle regime.

Equation 10

$$\Delta Y_t = \mu + \begin{cases} a_L ECT_{L,t-1} \\ a_H ECT_{H,t-1} \end{cases} + C_1 \Delta Y_{t-1} + \dots + C_p \Delta Y_{t-p} + \varepsilon_t$$

The hypothesis to be tested:

Equation 11

$$\begin{cases} H_0 : a_L = a_H = 0 \\ H_a : a_L \neq 0 \ or \ a_H \neq 0 \end{cases}$$

Seo (2006) employs the sup-Wald statistic and derives its asymptotic distribution based on a residual-based bootstrap to approximate the distribution. The asymptotic properties of the sup-Wal perfom well By the bootstrap procedure.

While applying models that allow the existence of regimes seems suitable as they are closer to the CO2-GDP dynamic, nevertheless a SETAR model assumes that the transition between them takes place suddenly rather than smoothly which is a unlikely behaviour of the variable analysed in this paper.

Accordingly in the last step a unit root test as proposed by Sollis (2009) is carried out. There are several tests which specify the unit root as null against the alternative of an exponential smoothing process TAR (STAR), but most of them assume symmetry under the alternative hypothesis. The novelty of Sollis (2009) is that in cases where the null hypothesis can be rejected, the test allows whether a ESTAR process is symmetric or asymmetric to be checked. Based on the proposal of Kapetanios et al. (2003) to overcome the problem of unidentified parameters under the null, Sollis suggests the following test:

Equation 12

$$\Delta Y_t = \emptyset_1 Y_{t-1}^3 S_t \left(\gamma_2, Y_{t-1}\right) + \emptyset_2 Y_{t-1}^4 + \sum_{i=1}^{k} k_i \Delta y_{t-i} + \eta_t$$

where the null hypothesis of the unit root is tested by:

Equation 13

$$H_0 \colon \emptyset_1 = \emptyset_2 = 0$$

If the unit root hypothesis can be rejected against the alternative of stationary symmetric or asymmetric ESTAR nonlinearity, the null hypothesis of symmetric ESTAR nonlinearity can then be tested against the alternative of asymmetric ESTAR nonlinearity:

Equation 14

$$H_0 \colon \emptyset_2 = 0, simetric\ non\ linear\ model\ ESTAR$$

$$H_a \colon \emptyset_2 \neq 0, asimetric\ non\ linear\ model\ \ ESTAR$$

Instead of assuming that the relationship between GDP and CO2 has a cointegrating vector (1, -1), in this article this assumption is relaxed, allowing for other possible stationary relationships rather than strict proportionality. Therefore, β can take different values in the following cointegrating vector:

$$GDP_{pc} - \beta CO_{2pc}$$

Figure 1 outlines the strategy that we will adopt in this article.

4. RESULTS

A previous analysis of the integration order is not necessary because in the event that neither CO2 nor GDP were integrated by Johansen methodology (1991) no cointegrating vector in the relationship CO2-GDP would be obtained.

Therefore, we begin with the cointegration analysis using the Johansen trace test. Table 1 shows the number of countries for which we can reject the null hypothesis of zero cointegrating relationships[2].

TABLE 1: JOHANSEN COINTEGRATION

Test	***Johansen (lag=2, trend)***	***Johansen (lag=3, trend)***	***Johansen (lag=4, trend)***
Nº of countries where cointegration exists: PIB-CO_2 I(0)	24	23	27

If up to four lags are specified in the Johansen test, major evidence of countries presenting cointegration is obtained. It is remarkable that of the 27 countries[3] only 7 countries (Belgium, Chile, Denmark, Netherlands, Switzerland, United Kingdom and United States) belong to the group of countries classified as developed.

At this point we consider whether linear methodology is appropriate to analyse variables such as CO2 and GDP, as their dynamics can be expected to be nonlinear for the reasons put forward in Section 2. Several indicators allow us to determine if there are indeed nonlinearities in the variables. However, and because our initial intuition is that the behaviour of CO2 and GDP is well characterised by the existence of different levels of the variables involving different regimes, a SETAR model is employed to verify if the existence of thresholds in both variables is significant. The empirical evidence is unequivocal, as for both CO2 and GDP series all countries have significant threshold.

TABLE 2: THRESHOLD EVIDENCE

Variable	***CO_2***	***PIB***
Nº of countries with significant thresholds	81	81

This strong evidence leads us to the implementation of a test that specifies threshold cointegration as a hypothesis such as in Seo (2006). Table 3 shows the scarce countries for which the hypothesis of no cointegration can be rejected. Specifically the only 9 countries are: Egypt, Mexico, Paraguay, Saudi Arabia, South Africa, Sri Lanka, Sudan, Tunisia and Zambia.

TABLE 3: THRESHOLD COINTEGRATION

Variable	***Seo Test (2006)***
Nº of countries where cointegration exists: PIB-CO_2 I(0)	9

However, the source of this high percentage of rejection could be the way that the transition between regimes is specified. However, this rejection can also be high as a result of how the transition thresholds are specified. To avoid the assumption of a sudden transition, a Sollis (2009) test is performed, allowing changes between regimes to occur smoothly. As can be seen in Table 4 the conclusions of this test vary substantially. The number of countries for which we can reject the null hypothesis of no cointegration increases considerably, since there is evidence of long-term equilibrium between GDP and CO2 for more than 50% of the sample. The results do not define a clear pattern of cointegration behaviour between developed and developing countries, as the countries for which the null can be rejected are: Algeria, Bangladesh, Bolivia, Cameroon, Canada, Côte d'Ivoire, Denmark, Ecuador, Egypt, El Salvador, Finland, France, Gabon, Ghana, Greece, Iceland, Indonesia, Israel, Italy, Japan, Jordan, Korea, New Zealand, Nigeria, Norway, Oman, Pakistan, Peru, Philippines, Portugal, Singapore, Sri Lanka, Sudan, Sweden, Switzerland, Syrian Arab Republic, Togo, Trinidad and Tobago, Tunisia, Turkey, United Kingdom, United States and Uruguay.

TABLE 4: NON LINEAR COINTEGRATION

(Smooth transition)

Variable	***Sollis (2009)***
PIB-CO_2 I(0)	43
Symmetric vs Asymmetric $\boldsymbol{H_0: \emptyset_2 = 0}$	16

As is reflected in equation 14, after rejecting the unit root null hypothesis in the GDP-CO2 relationship, we can assess whether the adjustments of the process towards its equilibrium are asymmetric. The last row of Table 4 shows that the symmetric adjustments can be rejected for 16 out of the 43 countries.

5. CONCLUSIONS

Nowadays there is a great concern for determining the relationship between economic development and the negative effects incidental to using certain types of energy. The goal here is to assess whether the GDP and CO2 macro-variables are in long-run equilibrium for 81 countries from 1960 to 2008. If this were so, it would have important implications, as it would be impossible to adopt any policy of environmental preservation without affecting growth. This can be determined methodologically by analysing whether the two variables are cointegrated, i.e. they share a common stochastic trend.

The relationship between GDP and CO2 and other contaminants has been the subject of numerous studies using the Granger causality methodology. However, the results reached previously are contradictory even when the same country is analysed. In this paper, the cointegration approach is applied to study the link between GDP and CO2. We propose the novel approach of assessing the CO2-GDP relationship in a nonlinear framework.

Nonetheless, our methodological strategy begins by applying a linear cointegration method to the GDP-CO2 relationship. Specifically, we use the trace test from Johansen (1991), obtaining evidence in favour of cointegration for a maximum of 27 countries.

However, there are several reasons that a priori seem to be appropriate in order to take nonlinearities into account (see section 3). In fact, the results validate this initial intuition, as if a SETAR model is used, evidence for significant thresholds for both the GDP and CO2 series are reached in all countries. These results validate the use of the threshold cointegration test proposed by Seo (2006). The null hypothesis of no cointegration can be rejected in few countries.

Nevertheless one of the criticisms to which this test is exposed is that while it allows for the existence of regimes, it considers that the changes between them take place suddenly. This implies that its conditional mean is not continuous as the threshold points are the discontinuous points. This disadvantage can be overcome by implementing Sollis's (2009) test, which, as it is based on a STAR model, allows smooth transitions between regimes to take place. An additional advantage of using Sollis' (2009) test is that, unlike many other tests of unitary roots, symmetry is not the only alternative hypothesis, so once the null hypothesis of the existence of the unitary root has been rejected, the symmetrical effects of the variable can be confirmed.

The results show that in about 53% of the sample analysed, GDP and CO2 are stationary, and therefore are in a long-term equilibrium.

The heterogeneity of countries analysed in this article makes it difficult to draw a clear pattern. In fact, most studies in the literature usually adhere to the study of one country or a homogeneous group of countries, allowing the identification of common features.
Although robust empirical evidence is not obtained to completely verify the acceptance or rejection of cointegration, the wide battery of contrasts applied to the series of the 81 countries allows, on one hand, the assertion that the cases in which cointegration exists are mainly less-developed countries.

On the other hand, this work aims to basically characterise relationships through aggregated data as a prelude to a richer analysis in terms of interaction channels, as both GDP and CO2 emissions are interrelated with other variables whose omission may lead to confusing results. Accordingly, the characteristics of each country regarding their dependence on energy, environmental regulation to which they are exposed, as well as the social idiosyncrasy and the stage of development must be taken into account when analysing the specific environmental performance of a particular group of countries.

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FOOTNOTES

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[1] See Levinson and Taylor (2008) for more detail.

[2] Additional details about the obtained results are available from the authors on request.

[3] Bangladesh, Belgium, Cameroon, Chile, People's Republic of China, Costa Rica, Denmark, Ecuador, Egypt, El Salvador, Honduras, Jamaica, Jordan, Mexico, Morocco, Netherlands, Nigeria, Pakistan, Paraguay, Saudi Arabia, South Africa, Sudan, Switzerland, Syrian Arab Republic, Tunisia, United Kingdom and United States.