ECONOMÍA MEDIOAMBIENTAL: DESARROLLO SOSTENIBLE

YURENA MENDOZA LEMES

Análisis de la relación entre Crecimiento Económico y el Medio Ambiente: consecuencias en el Cambio Clímatico y el Desarrollo Sostenible

Facultad de Ciencias Jurídicas y Económicas
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ENVIRONMENTAL ECONOMICS: SUSTAINABLE DEVELOPMENT

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An analysis of the relationship between Economic Growth and the Environment: consequences on Climate Change and Sustainable Development

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1

GENERAL INTRODUCTION

The huge increase in the world's greenhouse gases has led to increase the "threat" of climate change and global warming. While there may still be conflicting views on addressing the treatment of the climate change as a threat instead of as a reality, there is full consensus about the need to apply environmental protection measures for the sake of a sustainable development. However, the design of such measures is, at least, complicated due to the fact that policies will only be effective if they are global since it should be taken into account that greenhouse gases (hereinafter GHG) contribute to the environmental degradation regardless of the place where they are emitted. For this reason local, national or regional environmental policies won't be enough and there is a need for plans which should be as global as possible.

This feature turns the elaboration of measures to fight against climate change into a hard task, since it needs, first, to assess the necessary amount of reduction of emissions released into the atmosphere. In this first step, the complexity lies in the question of which is the target percentage that guarantees GHG's concentration at safe levels for sustainability, in fact there is an extensive debate on that subject among the environmental experts themselves. After this first step, in the design of international treaties individual targets should be assigned to each of the countries and this is where the most troubled point arises, since the potential candidate states to join disagree on the assignment criterion for allocating responsibilities.

One of these international treaties, and the most important one designed up to now is the Kyoto protocol, and the scheme to assign emission rights is the conflicting point among the parties, as representatives of developing countries claim that developed countries should be the ones to take the initiative in the fight against the reduction of emissions due to responsibility, equity and justice reasons. Any global program about Climate Change should be fair for all parties involved if it wants to be a successful program. In this regard, non-industrialized countries consider the current system to allocate emissions rights to be unfair, since the criterion used to design the individual targets in the Kyoto protocol was the reduction of emissions by an average of 5% for the 2008-2012 period on the basis of the levels the industrialized countries had in 1990.

This principle of allocation generates nonconformity in developing countries claiming two main reasons: the first one is that it is not fair, having in mind the developed countries are mainly responsible for the levels of concentration of gases in the atmosphere that have caused the feared climate change caused so far; the second one is that such criterion ignores the stage of development of the different countries as well as to other important criteria like population quantity of the countries that will sign that treaty.

These disagreements have caused emerging countries like China and India, which are key for the success of the mitigation of emissions plans, due to the amount of emissions they release, to be opposite to join the international treaties where developed countries are involved. These countries reject joining arguing that allocation criterion are unfair, alleging the responsibility of the industrialized countries, that are the ones that up to now have generated the high rates of pollution and therefore should be the ones to assume contractive measures of energy consumption. While the commitment of industrialized countries would help to the environmental conservation, it wouldn't be enough in any case, since the emerging countries in lower development stages, specialized in highly polluting sectors and with obsolete production structures, would be excluded, and the plan's effectiveness would be very limited.

Becoming clear that the success of the preservation policies will depend upon the comprehensiveness achieved with these, the international debate is focused on how to engage emerging economies that claim to grow without energy impositions just as the advanced economies did in the past.

Most authors of the environmental economics and sustainable development literature agree in pointing out certain key issues matters for achieving a global climate agreement such as:

- Which is the environmental performance of the developed countries?, Are their levels of emissions stable? Are they converging in their levels of emissions among the different industrialized countries?

- Do the environmental conservation policies cause negative effects on the economic growth of a country?

- Have the international environmental policies developed so far been effective?

- Is energy consumption the critical variable for economic growth?

This thesis attempts to answer these questions drawing conclusions about the behavior pattern of countries emissions, as well as from the key variables that must be taken into account to help in achieving the design of effective environmental policies.

Thus seeking to answer the first of the questions set out, Chapter II analyzes the CO_2 emissions behavior of industrialized countries, 22 OECD countries, to examine if there is convergence in the levels of emissions of the different countries, as well as the stochastic convergence among them.

There is extensive literature that analyzes if the countries are converging in their CO2 levels, finding mixed results. The analysis we performed in this chapter contributes to the field of environmental economic attempting to clarify the possible sources of the mixed evidence in the convergence of CO2 emissions among the countries. Specifically, we analyzed two possible sources of inconclusive results: firstly, the fact of neglecting the step prior to convergence analysis, may be misleading for researchers since the stationary nature of the original series would negate the possibility of stochastic convergence; secondly, have not taken into account the presence of potential nonlinearities in CO2 emissions series can lead to an unsuitable specification of the functional form in the analysis of these series and therefore draw the wrong conclusions.

To analyze these two hypothesis that may lead to distort the results, we relied on a detailed methodological strategy. First, we started performing linear tests proposed by Ng and Perron (2001). Next, using the Lee and Strazicich (2003) test, we will keep in mind the possible existence of structural changes in the series. Finally, we apply a nonlinear test within a Smooth Transition Autoregressive framework designed by Kapetanios et al. (2003). The empirical evidence obtained by our methodological strategy suggests that the original series of CO2 emissions for the longest time span considered, from 1870 to 2006, are stationary, therefore to continue evaluating the convergence in this context would be inappropriate. However, if we consider the period 1950-2006, CO2 emissions CO2 per capita are in a non-stationary local regime. Therefore, in this case, we proceed to study convergence. Bearing in mind the possible nonlinearities, convergence in CO2 emissions are evaluated using the Kapetanios et al. (2003) test, obtaining strong evidence of divergence among the 22 OECD countries. It is surprising that after analyzing the behavior of emissions from the other

OECD countries against the US as benchmark country, a strong empirical evidence is shown in favor of convergence. This result is alarming in the sense that the US is one of the leading countries in emissions which leads us to conclude that environmental performance of OECD countries is not as expected and therefore this makes it difficult to involve emerging countries in signing international treaties.

After the above results it is clear the need to impose measures that aim to stabilize the current levels of emissions release from advanced economies. However, at this point, the fear of whether said limitation of energy consumption damage or restricts the economic growth arises. This causes decision making in favor of environmental conservation involving much controversy. Therefore it is necessary to analyze to what extent there is a link between energy consumption and economic growth of countries (GDP is mostly used in the literature as proxy for economic growth). Thereby, it is capital to understand the behavior of series of CO2 emissions, energy consumption and economic growth, as these variables are critical for the effective and appropriate design of environmental policies in pursuit of sustainable development. More specifically, key information for policy decision makers in the design of effective measures against climate change may be the causal relationship between these variables. This is what we will do in Chapter III, where the relationship between the ratio of emissions and GDP in developed countries will be assessed. The methodological strategy to to analyze the above involves checking if the variables GDP and CO2 emissions are cointegrated and if it is so, to study the direction of causality of the relation CO2-GDP, that is, if energy consumption, and therefore the emissions, are causing growth, known as the growth hypothesis, or the opposite case that GDP causes emissions, called the conservation hypothesis. Alternatively the neutrality hypothesis would indicate that there is no causal link between both variables, and the feedback hypothesis postulates bidirectionality causality between both variables.

According to the prevailing hypothesis has different and important implications of economic policy which are key in the design of suitable policies to combat climate change. If evidence confirms the growth hypothesis, this means energy consumption is a critical input for growth, so policymakers are limited when implementing measure that encourage GDP, limiting, in turn, energy consumption and hence emissions. However if it is possible to verify that the conservation hypothesis exists, measures of environmental policy could be taken without adversely affecting growth, since the GDP causes the release of emissions. In the event that there is interdependence between CO2 emissions and GDP energy efficiency policies might not affect economic growth, and the "feedback hypothesis" would be verified. Finally, evidence in favor of the neutrality hypothesis states that neither a restrictive policy for energy consumption nor an expansive one would have any effect on GDP.

In Chapter III, unlike many studies studying the link between CO2 emissions and economic growth (GDP), we analyze causality between them using a Granger nonlinear methodology. For this purpose we perform the test proposed by Skalin and Teräsvirta (1999) to 10 highly developed OECD countries during the 1850 to 2008 period. For these countries, the empirical evidence clearly supports the relation bidirectional Granger causality between CO2 and GDP, thus validating the "feedback hypothesis". This result warns about the design of restrictive environmental policies in the release of emission emitted since these may have negative effects on the growth path.

From the design of these environmental policies, arises the most comprehensive and important agreement on reduction of greenhouse gases existing so far, the Kyoto Protocol, which sets as objective the reduction of emissions between 2008-2012. More specifically, the countries of the EU-15 were required to emit 8% less than what they did in 1990. After this target period, before a new design of a new protocol to expand the existing one, it is interesting to know to what extent progress has been made in fighting against emissions. At this point we consider if the long term pattern of the relationship energy consumption-GDP can reveal performance regarding reduction targets set in the Kyoto Protocol, thus replying to the third question set out at the be beginning this thesis. Methodologically we rely on the concept of cointegration. Cointegration implies that the difference between the series of energy consumption and growth is stable over time and shocks do not affect these differences because they are transitory. However, if GDP shows an increasing trend but the emissions level is not proportional, the long term relationship hypothesis, this is cointegration must be rejected. Thus, countries where cointegration not exits may comply with what was signed in Kyoto at relatively lower costs than those whose GDP trends and energy use share comovements over time, that is, when both variables are cointegrated. Again, in Chapter IV of this thesis, we rely on nonlinear methodology to assess the existence of cointegration. More specifically we use the test introduced by Kapetanios et al. (2003) and extended by Chong et al. (2008) that not only identifies the deterministic cointegration, but also a stronger concept such as the stochastic cointegration. The result reached reveals a clear pattern: Austria, Denmark, Italy, Netherlands, Portugal and Spain should achieve greater reductions of emissions between 2009 and 2012 if they want to achieve their respective targets set in the Kyoto Protocol.

Alternatively in the Appendix to Chapter IV we consider how to engage the emerging countries to achieve agreements as global as possible setting out two important questions when designing treaties that can be seen as fair by these countries: Does economic growth of the countries depend upon energy consumption?, Could a dependence pattern be established based on the stage of development of the country analyzed?. This is, it must examine whether the series of CO_2 and GDP of the countries are in equilibrium on the long term which means that any measure of energy consumption restraint designed by any agreement will have negative consequences on the energy growth. However, in this point is very important to know not only the relationships between variables in the long term but also the existence of catching up between both series since otherwise policies can be designed for a country that is not in equilibrium on the long-term that will have very damaging consequences for the growth path as despite that country not being in equilibrium the common trend of the country shows the existence of catching-up between the two variables. Methodologically speaking it is about assessing whether permanent movements in CO_2 emissions of a country are associated with permanent movements in GDP, that is, it is about to discern if the stochastic common elements are important and if there is a catching up process in the levels of both series. Therefore from the point of view of convergence between CO_2 and GDP we would be following the more robust version, stochastic convergence, developed by Bernard and Durlauf (1995). The results allow us certain classification of countries from the point of view of the degree of development achieved so far by them. For OECD economies, we found strong evidence of equilibrium on the long term while evidence of catching-up is clearer for emerging countries.

Following the analysis in Chapter IV, there is abundant literature which focuses on finding out if the energy consumption is the critical variable for economic growth. The evolution of this literature has consisted in trying to solve problems and criticism found in previous studies. One of the most common criticism is that previous studies focused on bivariate relationship between energy-consumption economic growth. Many authors attempt to solve this criticism using control variables. However the control-variables have frequently been chosen "ad hoc", following the subjective economic rationality of the authors. Our contribution to this literature is to apply a probabilistic model to select the explanatory variables between a long set of potential variables for the United States from 1949-2010, not only to perform an aggregate study but also a sector analysis. In other words we wonder, Is energy consumption which drives the path of US GDP or are there other more relevant variables?. This subject is addressed in Chapter V and we do it for USA. The choice of this country is due to mainly to three reasons: First, from the conclusions of Chapter I we can derive what already has been set out in other economic areas and that is that USA economy influences the behavior of the rest of countries; additionally, the importance of studying and analyzing one of the countries that is leading the world ranking emitting countries; thirdly and finally the access and availability of the data this country allows. The results found demonstrate the critical role of public expenditure and energy intensity when explaining the GDP. Besides, it becomes clear the importance of the sectoral study since the variables are different for each of the sectors.

2

RE-EXAMINING CO_2 EMISSIONS. IS ASSESSING CONVERGENCE MEANINGLESS?

2.1 INTRODUCTION

The effects of an increasing amount of greenhouse gases in the atmosphere and their unquestionable relationship with climate change have resulted in an enormous rise in the number of research studies attempting to clarify their economic effects. Within the field of environmental economics, most studies focus on carbon dioxide (CO_2), methane (CH4), oxygen, nitrogen (N2O), hydrochlorofluorocarbons (HCFCs), chlorofluoro-carbons (CFCs) and sulfur hexafluoride (SF6) as they are the main cause of global warming. The Kyoto Protocol is an unequivocal signal of the concern about these six gases, as all its actions are aimed at reducing them. However, the vast majority of studies focus on carbon dioxide, which makes sense consider-ing studies such as the Intergovernmental Panel on Climate Change (IPCC), which concludes that CO_2 is the largest contributor to the worsening of greenhouse effects. This assertion is based on the distinctive features of CO_2. It explains two thirds of the radioactivity resulting from greenhouse gases and it has the longest life cycle, remaining in the atmosphere for ap-proximately a hundred years. As a result, it is considered to be responsible for at least 61% of the global warming expected in the next 100 years Houghton et al. (1990).

Therefore, understanding the pattern displayed by CO_2 is a challenge that lies ahead for both politicians and international organizations responsible for ensuring environmental protection. Indeed, the success in the fight against climate change is crucially dependent upon a good analysis of carbon dioxide emissions. But more specifically, what are the reasons that make assessing CO_2 crucial?

- ***Efficient Energy Policy Design***

First, identifying the historical path and current trend of CO_2 emissions allows scientists to forecast the level of atmospheric concentration properly. This in turn implies that policy makers will know the extent to which CO_2 emissions should be reduced, a crucial issue to design efficient policy actions. Methodologically speaking, this involves examining the nature of the series. Stationary behavior of the carbon dioxide series means that shocks to emissions are temporary, that is, the series are mean-reverting, whereupon any policy adopted to cut emissions will have no effect in the long term.

According to McKitrick and Strazichic (2005) the IPCC scenarios, "which are of great influence on global warming predictions" are another example that shows the importance of knowing the nature of the CO_2 series. In particular, they pointed out that the scenarios may vary considerably in their projections depending on the assumptions regarding the nature of the series.

- ***Environmental Kuznet Curve Hypothesis (EKC): Correlation between Economic and Emissions Convergence***

Second, since the pioneering work by Grossman and Krueger (1991), several studies have provided results that support a positive correlation between a country's level of development and its level of CO_2 emissions [Selden and Song (1994); Grossman and Krueger (1995); Agras (1995); Agras and Chapman (1999)]. This has given rise to the so called Environmental Kuznets Curve (EKC) literature, which postulates that in the early stages of growth "environmental consumption" increases as a result of per capita income rising, which in turn leads to the degradation of natural resources. However, later, when development has reached a critical point, pollution levels begin to decrease as households demand improved environmen-tal quality, resulting in an inverted-U functional form. In other words, the EKC hypothesis assumes that economic growth is good for the environment.

Among others, Barro and Sala-i Martin (1991), Barro and Sala-i Martin (1992) and Evans and Karras (1996) have presented evidence in favour of economic convergence. Additionally Nahar (2002) finds evidence for absolute convergence among OECD countries. Therefore, if these countries are at the same stage of development and the EKC hypothesis holds true, they should also be converging in terms of emission levels. In this line of research, List (1999) is one of the first papers about emissions convergence that applied two indicators of environmental quality across U.S.A. regions over the period 1929-1994 to assess whether income convergence also implied air pollutant emissions convergence. Some support in favour of convergence was obtained using univariate unit root tests. Since then several studies have attempted to find empirical evidence on environmental convergence among groups of countries. As the global level of emission concentration is the most important target, spatial convergence of CO_2 may not seem important, but when it comes to being successful in environmental policy, as intended by the Kyoto Protocol, convergence is crucial.

- ***Wealth Transfer among Countries: Spatial Convergence Aims for the Largest Number of Countries Involved***

The essential multilateral agreement of Kyoto is not exempt from debate, but much of this dispute would be settled by a geographical distribution of CO_2 rights that would satisfy most of the signatory countries. There are two main controversial issues surrounding the Kyoto Protocol: the allocation of emission rights to each country, as well as the fact that those developing countries with higher growth rates are not committed to abiding by any target. Current emission quotas are based on the levels of greenhouse gases that the signatory countries released in 1990. Therefore, if there is a positive correlation between growth and emissions, this measure could be said to depend on the wealth accumulated by the nations to Kyoto's base year. There has been much discussion about how to distribute allowances. The survey by Bodansky (2004) gathered 40 alternatives to using historic levels, such as determining allocations according to the per capita emissions scheme (10 of them), or economic activity.

The allowance scheme is not trivial, as this might lead to a significant international re-distribution of wealth among the signatory countries, as shown in Aldy (2006). This author compares two distribution systems: one based on historical emissions (prevalent scheme at present) versus a hypothetical allocation per capita, according to each county's population in 1997. The resulting allocation of quotas is quantitatively very different in the two cases.

Stegman and McKibbin (2005)claimed that a per capita assignment of rights would be fair, because greenhouse gases are mainly the result of individual activities such as car use or electricity consumption. Stegman, in the same way as Aldy (2006), shares the concern about the 'assigned amounts' and potential wealth transfers. She recalls that fossil fuel distribution and consequently emissions are strongly correlated with the country's economic structure, its natural resource endowments, the level of development and its comparative advantage in the production of goods. Therefore, changes in the assignment of rights would lead to large adjustment costs and thus a wealth transfer among countries.

Hence it is vitally important for policymakers to know whether the countries that signed the Kyoto protocol are indeed converging in terms of per capita emissions.

Alternatively, the complex issue of how to involve the larger developing countries in the process of cutting their emissions has become circular. The United States exemplifies the attitude of those who will refuse to take on subsequent commitments unless emerging nations like China or India become engaged in constraints upon their emissions. This argument seems to be in accordance with the IPCC (2007), which asserts that now the less developed countries release more emissions than developed ones.

On the other side there are lobby groups and other groups of countries, especially devel-oping nations, that argue that justice and equity are achieved if the most developed countries are the ones who make the greatest effort. This argument is based on the supposed positive correlation between a country's level of development and its level of emission

The importance of reconciling positions is reflected in the GCI (1998) study, which assures that to involve the countries in a global climate agreement, emissions have to be allocated equally among all countries in a way that it is both achievable and seen as fair by all. The reduction in emissions resulting from the fulfilment of commitments made by developed countries in the first round of Kyoto negotiations will bring them onto a converging path, which is a sign of progress that would abet developing countries to take on ensuing environmental commitments.

2.2 CONTRIBUTION

In light of all the aforementioned reasons, it is undeniable that convergence deserves special attention. However, despite the different empirical techniques that have been used to assess it, the results are not conclusive. This may be due to two main causes.

- ***Neglecting the step prior to convergence analysis***

Firstly, due to reasons related to neglecting the step prior to convergence analysis, that is, the assessment of the order of integration of the original variables. If CO_2 time series were stationary, this would negate the possibility of stochastic convergence, as they are at different levels and therefore cannot converge with other series. In other words, in the case whereby stationary behavior countries have different levels of per capita CO_2 emissions, there is no possibility of convergence among them, clearly making testing for stochastic convergence irrelevant.

- ***Considering Nonlinearities***

The second source of ambiguous findings may come from the fact that previous studies have not taken into account the presence of potential non-linearities in the CO_2 emissions series. Thus, we employ a nonlinear methodology instead of the linear method commonly used in most studies. One potential reason for the non-linear behavior of this variable may be related to the combustion of fossil fuels, which is the main source of CO_2 emissions. The sectors that use the most fossil fuels are transport, utilities and production, all of which can be captured by the GDP indicator used as a proxy for economic activity.

Economic activity follows a trend characterized by peaks and troughs, showing periods of high relative growth during the so-called expansions and recessions when there is a relative decline in economic activity. The combination of both periods, the ebbs and flows of GDP, is called the business cycle. The relationship between GDP and CO_2 causes that the no regular pattern of economic activity is reflected also in the dynamics of emissions level. Therefore, GDP cyclical behavior with the non linear functional form (Beechey & Österholm, 2008) is likely to be found in the CO_2 emissions pattern.

To the best of our knowledge, no paper has tried to explain the nature of the CO2 series using a nonlinear approach. However, some authors, such as Lanne and Liski (2004), put "confusing findings" down to the use of linear methods, suggesting the use of nonlinear techniques for future analysis.

The functional form of the EKC is another reason why the linear methodology seems unsuited to capturing the behavior of CO2 emissions, as the majority of studies have used quadratic polynomial models to give support to the hypothesis of a long-run relationship between emissions and income levels, as an inverted-U form is assumed.

In the first place, this hypothesis involves a low regime that might correspond to countries in an industrialization stage characterized by a low level of income. In turn, economic growth at a later stage is accompanied by a high release of emissions. Then, when income levels reach a critical point, emissions begin to decrease. Thus, this emission pattern that suffers several structural changes could be well captured by a non-linear methodology.

This evidence should make us bear in mind that one should at least account for structural changes in the linear models. Only a few articles, as shown in Table 1, are concerned with how extraordinary events, such as oil crises or environmental policies, have affected emission trends. We highlight the research by Lanne and Liski (2004) as, apart from providing the exact timing of potential breaks, they performed a detailed analysis of the CO_2 pattern. They find that it displays two phases, so this could involve structural changes in the series.

In general, linear tests that allow for structural breaks in their deterministic structure impose that these changes occur instantaneously, implying that economic agents will react simultaneously to a given economic shock. However, if, for example an oil price shock occurs, economic activity, the main source of CO_2 release, does not cease suddenly. Actually, there is a delay in the response to the impact of a shock. The speed of the adjustment between the oil price increase and GDP falling depends on the level of economic development that each country has, its endowment of energy resources and its energy efficiency. Therefore these variables are characterized not by remaining unchanged, but by being quite inflexible in the medium term, so the effects of the shock effects surface after a certain period of time

Thus, instead of an instantaneous change in regimes, the transition occurs gradually.

This particular behavior of CO_2 emissions in response to a disturbance implies that Smooth Transition Autoregressive (STAR) models could be ideally suited to capturing this kind of behavior, as this model allows for deterministic components with a gradual rather than in-stantaneous adjustment and potential nonlinear dynamics in CO_2 emissions. Additionally, these models allow us to properly capture the pattern of economic cycles, which determines the pattern of emissions. Clearly, the switch from a recession to an expansion occurs gradually and is known as the transition period.

In short, this paper contributes to the existing literature by attempting to clarify the two possible sources of the mixed evidence on CO_2 emission convergence with a two-fold purpose: firstly, a good understanding of the underlying data generation process for carbon dioxide emissions; secondly, the results obtained in this first stage will determine emissions convergence validity. If countries emissions are at different levels, a stationary behavior of the series means that there would be no possibility of these countries converging. Accordingly, any conclusions drawn from studies of convergence would lead to misguided decisions.

As a result, we make explicit the necessary analysis of the original CO_2 emissions series employing a detailed methodological strategy. First, we use standard linear tests such as the those proposed by Ng and Perron (1995). Then we account for possible structural changes based on the tests designed by Lee and Strazicich (2003). Finally, we run a non-linear test, namely the one suggested by Kapetanios et al. (2003). This preliminary stage allows us to check whether the series are non-stationary, which determines if it makes sense to study stochastic convergence.

The rest of the paper is organized as follows. The next section briefly summarizes some previous studies that deal with the subject of convergence in CO_2 emissions. Section 3 describes the data and the empirical strategy employed in the analysis. Section 4 reports the results of applying different tests for various time-spans. The final section concludes.

2.3 PREVIOUS RESULTS

To the best of our knowledge, the literature on emissions convergence does not reach clear conclusions regarding convergence in CO_2 emissions. The vast majority of authors analyze convergence via unit root tests using a measure proposed by Carlino and Mills (1993). These authors tested for a unit root in the log of the ratio of per capita income relative to the average U.S. per capita income for eight American regions. This measure applied to CO_2 convergence implies using the log of the ratio of per capita emissions for each country "i", CO_{2it}, relative to the per capita emissions average of the sample, $\overline{CO}_{2t}$, i.e.:

$$\log\left(\frac{CO_{2it}}{\overline{CO}_{2t}}\right) \tag{1}$$

Using this measure, the authors investigate whether the emissions can be characterized by a unit root. If CO_2 exhibits a I(1) behavior, the effects of a shock are permanent, thus in region "i" there is no tendency for per capita emissions to converge towards the average (i.e.

to its compensating differential). However, if there is a disturbance but the series are stationary, quite the opposite response occurs: the series converge towards the sample average once the effects of the shock disappear. In other words, a unit root in the log relative series supports divergence, while the rejection of a unit root implies stationary or mean reverting behavior.

In an attempt to fill the gap between the empirical literature about pollution and income correlation (the EKC hypothesis), Strazicich and List (2003) presented the first article about per capita emissions convergence by examining a sample of OECD countries for the period 1960-1997. They employed the panel unit root test of Im et al. (2002)(2002, IPS) finding that spatial convergence has taken place. As an alternative approach, they analyze cross-section correlation between the initial level of output and the subsequent growth rates for a group of countries. In order to assess convergence, they carried out cross-section regressions. Obtaining a negative correlation implies convergence, since countries with low initial levels of output grow faster than those with higher output levels. Using this technique, Lee and Strazicich (2003) also present evidence in favor of convergence among a group of countries.

Lanne and Liski (2004)used unit root tests allowing for structural breaks to analyze the historical patterns of CO_2 emissions for a sample of 15 developed countries (an OECD subgroup) covering the period 1870-1998. Based on the EKC literature, they expected to find three phases in the emissions pattern of industrialized countries. The earliest phase dates back to the beginning of industrialization, which was characterized by fast growth through intensive use of coal, involving a large increase in the level of emissions. This was followed by a period of lower growth, a transition taking place from coal to gas and oil use. The third phase would start after the oil crisis in the seventies, when the main source of emissions release is fossil fuel, causing a reduction in the CO_2 trend.

Empirical evidence supports the existence of the first and second phases. However, only for two countries was the hypothesis of a decline in per capita emissions (that is, the third phase) significant. In contrast to Strazicich and List (2003), Lanne and Liski (2004) have found that the majority of the series are not stationary.

Similar to Lanne & Liski (2004), Lee et al. (2008) performed a unit root test allowing for a simultaneous break in the slope and level. Like previous studies, they analyze 21 OECD countries covering the period 1960-2000 and find emissions convergence.

Aldy (2006) applied the unit root test developed by Elliot et al. (1996) to a sample containing 88 countries from 1960 to 2000. They include 23 OECD countries in order to compare their results with those obtained by Strazicich and List. It is worth noting that for the selection of the optimal lag length for each country-specific DF–GLS test, Aldy (2006) applied the Modified Akaike Information Criteria (MAIC) of Ng and Perron (2001). He obtained that for only 13 out of 88 countries the null hypothesis of a unit root can be rejected at the 10% critical level, so convergence has not taken place. Only 3 of these 13 countries belong to the OECD. In spite of the disparity of their conclusions compared to those obtained by Strazicich and List, Aldy considers that the dissimilarities between the two studies are not inconsistent, but simply mean that stochastic convergence so far has been limited.

Barrasi et al. (2008) analyzed CO_2 convergence for 21 OECD countries between 1950 and 2002, giving support to the conclusions of Aldy. Actually, from the comparison with Strazicich and List (2003), and using the same methodology and a similar timespan, in contrast to the clear evidence of convergence obtained by LS (2003), Barrasi et al. (2008)found that 11 countries exhibit a unit root. This casts doubts on the degree of emissions convergence among OECD countries. Barrasi considered that the key to such differences is the criterion used to select the lag length. While Strazicich & List (2003) applied univariate ADF tests using the procedure "from general to specific" of Ng and Perron (1995), Barrassi et al. used the Modified Akaike Information Criteria (MAIC) developed by Ng and Perron (2001) for each auxiliary regression. This criterion includes a penalty factor that is dependent upon the order of the autoregression. Furthermore, the MAIC can be adapted to the deterministic components contained in the regressions. Hence the author concludes that the sample of OECD countries diverges and refers to overparameterisation to explain his discrepancy with Strazicich and List.

Westerlund and Basher (2008) emphasized the differences between their study and those by Strazicich and List (2003) and Aldy (2006). The most significant difference is that they use panel data tests to examine and explain the high persistence of the CO2 series. Accordingly, they introduce a factor model to adjust the data to cross-section dependence.

Compared to previous studies, this factor model is interesting as it discerns the common elements of all the countries in the panel from those purely idiosyncratic. Given that many analyses focus on countries that employ environmental protection policies (as in the case of the European countries that have ratified Kyoto), it is important to isolate potential co-movements among them from those related to sectoral specialization that each country would display.

Table 1: Previos Empirical Studies

AUTHOR/S	DATA BASE	SAMPLE	METHODOLOGY	RESULTS
List and Strazicich (2003)	WDI (2004)	21 OCDE COUNTRIES 1960-1997	LINEAR. MEASURE: Carlino and Mills (1993) TEST: Im et al. (2002)	CONVERGENCE
Lanne and Liski (2004)	CDIAC	16 OCDE COUNTRIES 1870-1998	LINEAR. MEASURE: Log per capita. TEST: Unit Root with one/multiple break/s. Vogelsang and Perron (1998)	10/16 Original Series STATIONARY
Aldy (2006)	CDIAC	23 OCDE COUNTRIES 1960–2000	LINEAR. MEASURE: Carlino and Mills. TEST: a GLS DF test developed by Elliott et al. (1996) & MAIC.	Mixture: Traditional test: DIVERGENCE Test Elliott et al : 13/21 CONVERGENCE
Barrassi (2008)	CDIAC	21 OCDE COUNTRIES 1950-2002	LINEAR. MEASURE: Carlino and Mills. TEST: Im et al. (2002)	DIVERGENCE
Westerlund and Basher (2008)	CDIAC	28 OCDE COUNTRIES 1870-2002	LINEAR. MEASURE: Evans (1998). TEST: Three panel: Phillips and Sul (2003), Bai and Ng (2004) and Moon and Perron (2004).	CONVERGENCE
RomeroÁvila (2008)	for Economic Co-operation and (OECD)	23 OCDE COUNTRIES 1960–2002	LINEAR. MEASURE: Carlino and Mills. TEST: Panel unit root test developed by Carrion-i Silvestre et al. (2005)	CONVERGENCE
Lee, Chang and Chen (2008)	WDI (2004)	21 OCDE COUNTRIES 1960–2000	LINEAR. MEASURE: Carlino and Mills TEST: Unit root test proposed by Sen (2003)	CONVERGENCE
Lee et al. (2008b)	WDI (2004)	21 OECD COUNTRIES 1960-2000	LINEAR. MEASURE: Carlino and Mills. TEST: panel SURADF β and σ convergence	DIVERGENCE: By panel SURADF and β and σ convergence 7/21 NON-STATIONARITY
Lee-Chang (2009)	CDIAC	21 OECD COUNTRIES 1950-2002	LINEAR. MEASURE: Carlino and Mills. TEST: Panel unit root test developed by Carrion-i Silvestre et al. (2005)	CONVERGENCE

For this purpose Westerlund and Basher carried out a unit root test in two steps. First they estimate and subtract the common components of the CO_2 series and then check for convergence. As shown in Table 1, they use the measure suggested by Evans (1998). The idea is that the long-run CO_2 gap between any two countries must be stationary. From the results of Ericsson and Halket (2002), Westerlund and Basher (2008) have argued that Carlino and Mills' (hereafter C&M) definition is a weak measure of convergence, since the emissions of two countries could be diverging deterministically. They find convergence in per capita emissions across a sample of 28 countries, 12 of which are emerging nations, over the period 1870-2000.

Similarly, Romero-Ávila (2008) and Lee and Chang (2009) have applied a panel unit root test developed by Carrion-i Silvestre et al. (2005) which allows adapting general forms of cross-sectional dependence. In turn, this test assumes a highly flexible trend function by incorporating an unknown number of structural breaks. It is noteworthy that they consider not only stochastic, but also deterministic convergence. This concept of convergence is related to the research by Westerlund and Basher (2008), as they both try to discern common from idiosyncratic elements.

Lee et al. (2008b) also chose a panel unit root test that could take into account the likely presence of serial correlation among the countries studied. More precisely, they use the SURADF unit-root test suggested by Breuer et al. (2002), which in addition to dealing with correlation, allows to individually determine whether a country exhibits stationary behavior. Their results point towards divergence since over a sample of 21 OECD countries, only seven CO_2 series are I(0).

In summary, the general conclusion we can draw from the empirical evidence is that findings are not unanimous. However it is remarkable that except for Aldy (2006) and Lanne and Liski (2004), these papers do not present the stationarity analysis of the original CO_2 series. If the original CO_2 series are stationary, to study convergence using C&M or Evans definitions can be misleading, as both concepts assume the non stationarity of the individual variables assessed. Indeed, applying C&M to variables that are already stationary would imply subtracting two stationary series, which results in another I(0) process. Therefore, the information above reveals that it is crucial to determine if the original series are stationary prior to assessing stochastic convergence.

2.4 METHODOLOGICAL STRATEGY

In the rest of the paper we are going to focus on analyzing the original CO_2 series, aiming to find the cause for so many inconclusive results in the literature of convergence. To this end, we are going to develop and carry out a testing strategy. First, we apply standard linear unit root tests. However, these tests have low power, as noted by Perron (1989), when the presence of a structural break is ignored. Therefore, in order to ensure that this does not occur in the analysis of CO_2 emissions, in a second stage we apply tests that take into account structural changes, using the tests proposed by Lee and Strazicich (2003).

Due to the specification of their deterministic structure, neither standard linear tests, nor those that allow capturing breaks in the slope or level of the series, are able to detect possible non-linearities in the series. If the series display non-linear dynamics, the former tests do not spuriously reject the unit root null hypothesis, as they tend to confuse nonlinearities with a unit root. Therefore, we finally implement the test proposed by Kapetanios et al. (2003).

2.4.1 *Standar Linear Tests*

Ng and Perron (1995) proposed the MZ_t^{GLS} tests which is a modified version of Z_t (originally designed by Phillips and Perron (1989) based upon Generalized Least Squares (hereafter GLS) detrended data. Elliot et al. (1996) suggested detrending the data in order to improve the power of the tests and, according to Ng and Perron (2001) , should be used in conjunction with a suitably chosen k.

$$MZ_\alpha = Z_\alpha + \left(\frac{T}{2}\right)(\hat{\alpha} - 1)^2 \tag{2}$$

$$MZ_t = Z_t + \left(\frac{1}{2}\right)\left(\frac{\sum_{t=1}^{T} y_{t-1}^2}{s^2}\right)^{\frac{1}{2}}(\hat{\alpha} - 1)^2 \tag{3}$$

Ng and Perron (2001) argued that the selection of the lag truncation (k) plays a crucial role in the size of the unit root test. Traditional information criteria, such as the AIC and BIC tend to select a truncation lag that is too low. This can provoke Type I errors (that is, rejecting the null hypothesis of non-stationarity when true). In particular, when there are errors with a moving-average root close to -1, a high order augmented autoregression would be necessary to avoid over-rejecting the null hypothesis of a unit root. In order to account for this type of problem, they suggest using a modified AIC (MAIC) instead with a penalty factor that is sample dependent.

2.4.1.1 *Linear Tests Allowing for Structural Change*

Although the Ng and Perron (1995) tests have good properties, the omission of structural breaks can provoke a severe loss of power. In order to prevent this, in a second stage we have applied unit root tests that allow for structural breaks. We have chosen an LM test formulated by Lee and Strazicich (2003) that endogenously determines the presence of structural breaks. The following data generating process (DGP) is considered:

$$y_t = \delta' Z_t + e_t$$

where Z_t is a vector of exogenous variables and the error term is as follows:

$$e_t = \beta e_{t-1} + \epsilon_t,\ \epsilon_t \sim iid\ N\left(0, \sigma^2\right)$$

Although the authors define three types of models, we have only applied model C, the one that allows for a change in both the intercept and the trend. The deterministic components can be described by

$$Z_t = [1, t, D_{1t}, D_{2t}, DT_{1t}, DT_{2t}]'$$

where $D_{jt} = 1$ for $t \geq T_{Bj} + 1, j = 1, 2$ and 0 otherwise. T_{Bj} denotes the time period when the breaks occur. $DT_{jt} = t - T_{Bj}$ for $t \geq T_{Bj} + 1, j = 1, 2$ and 0 otherwise.

Therefore the LM unit root test can be written as:

$$\Delta y_t = \delta' \Delta Z_t + \phi \tilde{S}_{t-1} + u_t \tag{4}$$

where $\tilde{S} = y_t - \tilde{\psi}_x - Z_t\tilde{\delta_t}, t = 2, ..., T$; $\tilde{\delta_t}$ are the coefficients in the regression of Δy_t on ΔZ_t; $\tilde{\psi}_x$ is given by $y_{1t} - Z_1\tilde{\delta_t}$. Finally, the null hypothesis is $\phi = 0$.

2.4.2 *Non Linear Unit Root Tests*

Kapetanios et al., (2003, KSS hereafter) proposed a unit root test against a globally stationary ESTAR process. As shown in the article, the following data generating process is considered:

$$y_t = \beta y_{t-1} + \gamma y_{t-1}\Theta(\theta; y_{t-d}) + \varepsilon_t \qquad t = 1, ..., T \tag{5}$$

This is a STAR (1) model where there are unknown parameters. Kapetanios et al. (2003) assume that the transition function adopts an exponential form,

$$\Theta(\theta; y_{t-d}) = 1 - e^{\left(-\theta y_{t-d}^2\right)} \tag{6}$$

where $\theta \geq 0$, whereas $d \geq 1$ is the delay parameter. The transition function is bounded between 0 and 1 and is symmetrically U-shaped around zero:

$$\Theta : \mathbb{R} \rightarrow [0, 1]\,; \qquad \Theta\,(0) = 0 \qquad lim_{x\rightarrow\pm\infty}\Theta\,(x) = 1$$

Thus the model obtained is an exponential STAR (ESTAR):

$$y_t = \beta y_{t-1} + \gamma y_{t-1}\left[1 - e^{\left(-\theta y_{t-d}^2\right)}\right] + \varepsilon_t$$

which can be reparametrized as:

$$\triangle y_t = \phi y_{t-1} + \gamma y_{t-1}\left[1 - e^{\left(-\theta y_{t-d}^2\right)}\right] + \varepsilon_t \tag{7}$$

with $\phi = \beta - 1$.

Note that the KSS test adds nonlinear autoregressive dynamics to the linear autoregressive structure. Therefore, in order to test whether the process is stationary we must account not only for the parameter ϕ but also for γ. Thus linear tests such as that proposed by Ng and Perron might fail to reject the null of nonstationarity since they only test for the value of ϕ. Linear tests might therefore mistake the presence of non-linearity with the existence of a unit root.

The KSS test goes a step further in order to test whether the data contains a unit root by taking into account both parameters, the one corresponding to the linear structure as well as the nonlinear one (ϕ and γ). Therefore even if $\phi \geq 0$ the series could be stationary, subject to $\gamma < 0$ and $\phi + \gamma < 0$. In this case the process is globally stationary rather than nonstationary.

It is assumed that $\phi = 0$, implying that y_t follows a unit root process in the middle regime. Additionally for $d = 1$,

$$\triangle y_t = \gamma y_{t-1}\left[1 - e^{\left(-\theta y_{t-d}^2\right)}\right] + \varepsilon_t \tag{8}$$

To test for a unit root in the presence of nonlinearities, Kapetanios et al. describes the null hypothesis as $H_0 : \theta = 0$ which implies a unit root process, against the alternative $H_1 : \theta > 0$; then, y_t follows a nonlinear but globally stationary process.

Testing the null directly is not feasible since γ is not identified under the null. Kapetanios et al., following Luukkonen et al. (1988), overcomes the problem using a t-type test statistic. Computing a first-order Taylor series approximation to the ESTAR model under the null, the resultant auxiliary regression is obtained:

$$\triangle y_t = \delta y_{t-1}^3 + error \tag{9}$$

From this regression a t-statistic can be obtained to test the null hypothesis $\delta = 0$ against the alternative $\delta < 0$, so that:

$$t_{NL} = \frac{\hat{\delta}}{s.e.\left(\hat{\delta}\right)}$$

where $\hat{\delta}$ denotes the OLS estimated parameter δ and *s.e.* is the standard error of $\hat{\delta}$.

To correct for possible serially correlated errors in (8), Kapetanios et al. suggest extending the model (9):

$$\triangle y_t = \sum_{j=1}^{p} \rho_j \triangle y_{t-j} + \delta y_{t-1}^3 + error \tag{10}$$

2.5 DATA AND EMPIRICAL RESULTS

2.5.1 *Data*

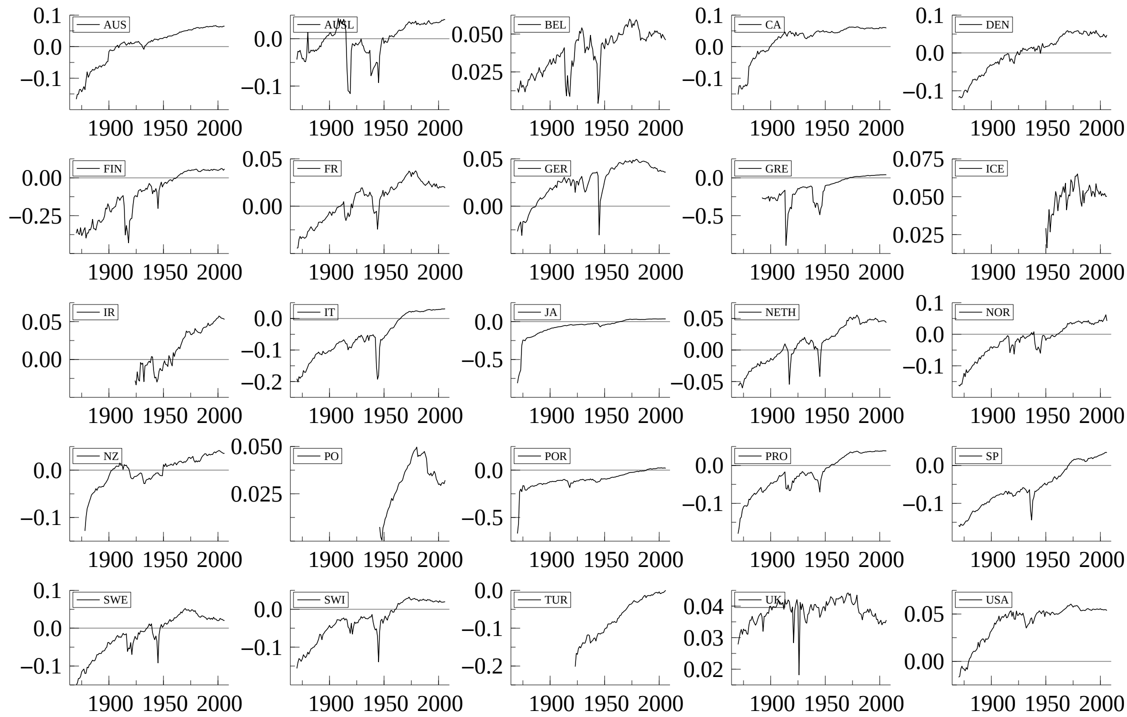
We have computed the tests using data for 22 OECD countries [1]. The data on national total fossil fuel CO_2 (metric tonnes) has been obtained from Marland et al. (2006), whereas the population data comes from Maddison (2006).

In this paper the period covered spans from 1870 to 2006. However we have split it into sub-periods to allow both a direct comparison with previous studies summarized in Table 1, as well as to ascertain whether the CO_2 emissions depend on the occurrence of significant events. Thus, we allow for three sub-periods between 1870 and 2006.

Apart from the whole sample, the first sub-period that we consider starts in 1870, a date that has been selected to avoid the potential effects of outliers at the beginning of the database. As pointed out by Lanne and Liski (2004), many of the countries currently classified as developed were in their early years of industrialization around 1870. Moreover, the period running up to the 50's may be a suitable time to capture the potential effects on CO_2 of extraordinary events such as WWII, the oil crisis, as well as the highest economic growth of developed countries, which results in a sharp increase in CO_2 emissions.

1 The countries considered are: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece (available data from 1892), Ireland (available data from 1924), Italy, Japan, Netherlands, New Zealand (available data from 1878), Norway, Portugal, Spain, Sweden, Switzerland, Turkey (available data from 1923), United Kingdom and the US.

Figure 1: CO_2 emissions per capita



2.5.2 *Results*

In this section we present the empirical evidence that we have obtained following the same order described in the methodological section[2]. First, we apply the linear test proposed by Ng and Perron (2001) to the CO_2 emissions series and select the lag order using the MAIC criterion. Table 3 summarizes the number of countries that are found to be I(0). The outcome is that required in order to confirm the significance of the conclusions drawn from the works listed in 1: regardless of the particular sub-sample chosen, the majority of the CO_2 series can be considered non-stationary. However, this evidence is not sufficient to conclude in favor of I(1) variables, since both the presence of

2 For restriction on length we only provide only a summary of the results. Detailed results are available from the author on request.

nonlinearities in the CO_2 data and possible structural changes make standard linear tests such as Ng and Perron (2001) biased towards nonstationarity.

As can be seen in Figure 1 we graph the logarithms of CO_2 per-capita emissions for each country. All the variables exhibit, during the sample period, at least one discontinuity along the whole span, thus we must ensure that these discontinuities are not affecting the power of the unit root tests.

The seminal paper of Perron (1989) already describes the important effects that structural changes have on the power of the ADF unit root test. Even if the Ng and Perron tests have better power properties than the classical ADF unit root tests, they also tend towards non-rejecting the unit root null when the deterministic specification omits a structural break. If this is the case, the results obtained using the Ng and Perron tests could have been affected by the low power of the test. This matter has already been proven by Lanne and Liski (2004) and Lee et al. (2008a)[3].

Thus, in order to improve the specification of the tests, we should allow for changes in the deterministic components of the CO_2 series, since it is necessary to take into account possible structural changes due not only to the different processes of industrialization undergone by the countries, but also to the occurrence of extraordinary events such as environmental policy considerations or the oil crisis.

Therefore, we have applied the tests formulated by Lee and Strazicich (2001), which take into account potential breaks that could occur both in the slope and level. Later, Lee and Strazicich (2003) extend the test to capture up to two changes, which are described in Table 3 as

3 See section Previous Results.

Table 3: Summary of the Linear Test

TOTAL SERIES I(O)					
Series start at	MZ_t^{GLS}	**L(1)**	**S(1)**	**L(2)**	**L(2)S(2)**
1870	3/21	7/21	4/21	7/21	8/21
1900	4/21	7/21	5/21	7/21	6/21
1950	0/23	0/23	5/23	0/23	7/23

Note: MZ_t^{GLS} is the test defined by Ng and Perron (2001). The last four columns show the results of the tests suggested by Lee and Strazicich (2003) . "L" and "S" stand for a break that occurs in the level and in the slope respectively. The number of changes are in parentheses. See section **??** for details.

The asymptotic null critical values for these tests are detailed in Table 11 in the Annexes.

Turkey data starts at 1923 and Ireland at 1924. Therefore when series start at 1870 and 1900 respectively, there are 21 series under consideration since $\overline{CO}_{2t}$ process is also included.

"L" and "S" when a break occurs in the level and slope respectively, where the number of breaks are in parentheses.

The importance of the possible structural changes[4] is highlighted, as, in 1870 and according to the MZ_t^{GLS} test, the maximum number of I(0) variables is 3 out of 21. Once we allow for two breaks, the L(2) S(2) test finds 8 out of 21 countries stationary. The number of countries originally stationary is high enough to alert us about the convenience of embarking on the study of emissions convergence, 30 and 38 percent of the sample for the periods starting at 1870 and 1950 respectively.

The methodology proposed by Carlino and Mills (1993) involves defining the ratio of CO_2 per capita emissions relative to the average CO_2 per capita emissions for each country "i". We have applied both the tests of Ng and Perron and List and Strazicich to the aver-

4 Although our purpose is not to estimate the exact moment of the breaks, we present in table 12 the breaks clustered according to the span where they happened. Roughly speaking most of the breaks occur from 1950 onwards.

age of CO_2 emissions per capita and conclude that the evidence in favor of stationarity increases, as we adjust the model accordingly to the characteristics of the series, we obtain unit root tests more suited to capturing the pattern displayed by CO_2 emissions. Therefore, by applying Carlino and Mills measure we would be subtracting two stationary series. As we have shown that a significant proportion of the original CO_2 series are stationary, we would be analyzing a linear combination of two I(0) series, which also results in a stationary series.

We have shown above that stationarity analysis varies significantly if we do not account for structural changes in CO_2 emissions. Hence, we can also ask ourselves what would happen if in addition we modified the functional form so that the model could capture nonlinearities in CO_2 emissions.

This is achieved by using smooth transition autoregressive (STAR) models, which can help us to overcome potential problems that arise from the use of the linear tests. The autoregressive structure of Ng-Perron Ng and Perron (2001) and Lee and Strazicich (2003) tests is linear. As a result, if the series of CO_2 exhibit non-linear dynamics, these tests fail to assess the order of integration of the variables. Using a test within STAR framework such as the Kapetanios et al. (2003) test, we can accommodate a more suitable alternative hypothesis: the variables can in reality be non-linear although globally stationary.

Kapetanios et al. (2003), Sercu et al. (1995) or Michael et al. (1997) have shown that the ADF test may have low power when the true process is nonlinear, yet globally stationary. Similar power problems can be associated to the Ng and Perron tests. The results of the KSS non-linear test are reported in Table 5. Note that depending on the chosen criteria for the lag order in the auxiliary regression, the num-

Table 5: KSS Nonlinear Test

TOTAL SERIES I(O)				
Series start at	AIC	BIC	HQ	MAIC
1870-2006	9/21	8/21	8/21	8/21
1900-2006	11/21	11/21	11/21	10/21
1950-2006	9/23	10/23	10/23	5/23

ber of countries for which we can reject the null hypothesis of the unit root differs slightly.

The comparison of the results for the first three sub-periods in Table 3 and those obtained using the KSS test, shows that the linear tests fail to reject the unit root when the process, instead of being I(1), is nonlinear but globally stationary.

In Table 3 for the longest sample size, the Ng and Perron test rejects the null hypothesis for only 3 out of the 21 countries. Thus the majority of the original CO_2 series are non-stationary. However, using the KSS test and the MAIC selection criterion for the lag order, the unit root null hypothesis can be rejected for at least 9 out of 21 countries.

The fact that the MZ_t^{GLS} fails to reject the null in the presence of nonlinearities is even more evident if we consider the 1900-2006 sub-period, as the number of countries found stationary is larger than from 1870 to 2006. Indeed, regardless of the criterion chosen being the AIC, BIC or HQ, 52 per cent of the countries are stationary according to the KSS test, a sufficiently high percentage to consider that the CO_2 emissions are I(0)[5]. However, for the sub-period 1950-2006, the drop in the proportion of I(0) countries found is remarkable. More specifically, using the MAIC criterion, the number of countries decreases considerably. This fact may reveal that from 1950 onwards,

5 see Table 5

CO_2 emissions are in a local non-stationary regime. Additionally, as we have shortened the time span, the historical information of the process is lost. Therefore, it is more difficult for a mean reversion of the series to occur after a shock.

Note that one of the main features of STAR models is that they allow the process within a particular regime to be nonstationay but, nonetheless, the overall process could be stationary, so the loss of information encumbers one of the critical advantages of these models. Therefore, the 56 observations between 1950 and 2006 do not exhibit a globally stationary behaviour. Furthermore, these results are compatible with those obtained using the List and Strazicich tests, where the majority of breaks are located between 1950 and 2006, as has been reported in Table 12.

Going back to Table 1, where we report previous empirical papers and results, in seven of them the samples begin after 1950. Assuming the non-stationarity of the original CO_2 series from the 1950s onwards allows us to continue with the convergence study. The importance of the criterion chosen cannot be overemphasized, since we analyze convergence among countries due to the choice of the strictest criterion as this improves the power of the test and avoids an over-rejection of the unit root null hypothesis in favor of stationarity. However, following other less stricter criteria, the decision to go ahead with a study of convergence would be questionable since the number of countries found I(0) is sufficiently high.

After checking CO_2 behavior, based on the stricter criterion MAIC, the evidence now allows us to assess the existence of convergence from 1950 onwards. This ensures that policy conclusions concerning environmental action that could be taken are based on robust econometric results. For this purpose, we use the KSS test to analyze the existence of convergence between these 22 OECD countries, employing two different measures.

The first of them is the abovementioned definition proposed by C&M, as shown in equation (11). The results are presented in Table 6 below, where each column corresponds to the selection of lags according to different criteria. Using the first three criteria, there are 7 countries[6] that converge using the AIC, while there are 9 and 8 cases according to both the BIC[7] and HQ[8] criteria respectively. However, the number of countries that are converging is lower[9] if we chose the MAIC as the lag order selection criterion.

Table 6: Number of countries Converging according to the definition of C&M

TOTAL SERIES I(O)				
Series start at	AIC	BIC	HQ	MAIC
1870-2006	17/20	15/20	16/20	13/20
1950-2006	7/22	9/22	8/22	5/22

As can be seen in Table 4, we have also checked the result using the C&M measure for the period 1870-2006, the outcome confirming the premise of this paper: in the period 1870 original CO_2 variables are mostly stationary and since the average emission, $\overline{CO_{2t}}$, is stationary, it is entirely logical that the combination of stationary time series lead to a new I (0) process.

To summarize, after concluding that the variables are I(1) from 1950 to 2006, we have analyzed the existence of convergence based on the

6 Australia, Ireland, Netherlands, New Zealand, Norway, Sweden and Switzerland.

7 Using the BIC criterion convergence is found for the same group of countries, including in this case Finland.

8 Using the HQ criterion convergence is found for the same group of countries as using the AIC criterion.

9 Using the MAIC criterion convergence is found for the same group of countries as using the BIC criterion, with the exception of Ireland and Switzerland.

C&M criterion. Moreover, we have taken into account possible non-linearities in the CO_2 emissions series. As in the previous literature, there is evidence in favor of convergence, but it is not conclusive.

Therefore, this paper contributes to clarify two possible reasons for the mixed evidence on convergence. On the one hand, omitting the analysis of the order of integration of the variables prior to going ahead with the study of convergence and on the other, the fact that previous studies have not taken into account the presence of potential non-linearities in CO_2 emissions. The conclusion we have reached is that, according to the C&M convergence criterion, there is no strong evidence of convergence among the 22 OECD countries we have studied.

At this point a new issue arises which challenges our above conclusion: Is the C&M definition the most appropriate way of assessing convergence? Indeed, this measure, as it is based on average CO_2 emissions, includes very unequal countries such as Switzerland, with approximately 0.60 per capita emissions on average, together with countries such as Denmark and the US with a mean of 2.60 and 3 per capita emissions respectively.

In order to show that this measure is biased towards countries such as the US and, thus, it presents high dispersion, we substitute the emissions average in the C&M criterion by the differential with the CO_2 emissions level for the USA , i.e.

$$\log\left(\frac{CO_{2it}}{\overline{CO}_{2USAt}}\right) \tag{11}$$

Table 7 summarizes the results obtained using this new measure, which are very similar to the previous ones. This is due to the large weight of US emissions in the sample mean.

Table 7: Convergence with the US as a Benchmark

NUMBER OF COUNTRIES CONVERGING US AS A BENCHMARK				
Series start at	AIC	BIC	HQ	MAIC
1950-2006	**6/23**	**10/23**	**8/23**	**4/23**

The election of the U.S. as a benchmark is a wholly consistent measure, considering the abovementioned relationship between GDP and emissions, since The US is the world's largest economy and acts as a leader in international growth patterns. However, at this point, we must also consider the economic implications of the alarming conclusions that the countries analyzed are converging towards the U.S., the major per capita polluting country. Therefore, this kind of empirical evidence should be considered by policy makers, because it seems that the more developed countries are not heading in the right direction in regard to combating Climate Change.

2.6 CONCLUSIONS

The results of empirical studies on CO_2 emissions convergence have so far been inconclusive. However, prior to assessing convergence, it is necessary to know the nature of the original CO_2 series, that is, whether they behave as stationary processes. If this analysis is omitted and emissions are originally stationary, an assessment of convergence using this series might be meaningless, which in turn can lead to misleading conclusions concerning crucial policy decisions aimed at combating Climate Change.

The source of the ambiguous findings may stem from the fact that the authors understate the importance of an adequate characterization of the CO_2 data generating process, or perhaps because the methodology used is not the most appropriate for capturing the pattern of CO_2 emissions.

Accordingly, this paper contributes to the field of environmental economics by clarifying two possible reasons for the mixed evidence on CO_2 emissions convergence: on the one hand, overlooking, or at least not making explicit, the necessary analysis of original CO_2 emissions series, as a preliminary step to be taken in order to ascertain whether the series are non-stationary. To this end we followed a detailed methodological strategy starting with standard linear tests such as those proposed by Ng and Perron (1995) and then taking into account possible structural changes by applying the tests designed by Lee and Strazicich (2003).

This detailed strategy ends employing second a non-linear test, namely that proposed by Kapetanios et al. (2003), as the source of ambiguity could stem from the fact that previous studies have not taken into account the presence of potential non-linearities in the series of CO_2 emissions. Thus, we employ a nonlinear methodology instead of a linear one, which is the approach taken in most of the preceding studies.

The reason for using a nonlinear methodology is the fact that the main source of CO_2 emissions is economic activity, which goes through cycles of growth and stagnation. This means that the release of emissions directly depends on the economic cycle. In other words, the level of emissions fluctuates, increasing if the economy is expanding and decreasing when the economy enters recession.

Fluctuations over time between periods of growth and those of decay have an impact on the level of CO_2 emissions. Shifts between these periods of expansion characterized by a higher CO_2 release, and recessions with a lower level of economic activity, which cause fewer emissions, occur gradually instead of instantaneously. These dynamics are well captured by switching-regime models, allowing the economic agents to react once time elapses, which can be captured by a transition function. Smooth Transition Autoregressive (STAR) models are particularly well-suited to this task. Consequently, in this paper we examine the behavior of CO_2 emissions for 22 OECD countries using the unit root test suggested by Kapetanios et al. (2003) within a STAR framework.

In order to make direct comparisons with previous empirical results, the period analyzed (1870 to 2006) is split into three different sub-periods. At the same time, the sub-samples help us to determine the effects of extraordinary events on CO_2 emissions.

After completing our strategy to test for CO_2 behavior, the empirical results obtained for the two widest spans, that is from 1870 to 2006 and from 1900 to 2006, show clear evidence in favor of stationarity of the original CO_2 series. These findings appear to challenge the conclusions reached in previous studies of convergence that cover similar periods.

However from 1950, after the Second World War, original CO_2 emissions appear to be in a local non-stationary regime, as we have shortened the time-span and therefore do not include all the observations in the model. Thus, the 56 observations between 1950 and 2006 do not allow the series to be globally stationary. These findings are consistent with those obtained with the List and Strazicich test, where the majority of the breaks are located in the latter period, from the 1950s onwards. As the variables are I(1) for this period, the study of stochastic convergence (implying the stationarity of the difference between the two variables) is fully relevant.

For this reason we use the definition by Carlino and Mills, which is the most commonly used. The results are that a maximum of 9 out of 23 countries converge which coincides with the number of countries found I(0) in the preliminary step where the order of integration of the countries was assessed. This measure may not be appropriate to evaluate such unequal countries on their per capita emissions, as is the case of Switzerland and the US. With the purpose of showing the weight of the US in the average of the C&M measure, we re-evaluate the countries by comparing them to the US, reaching very similar findings. In future research we believe that it would be useful to employ a measure characterized by lower dispersion than the C&M definition.

These results have crucial political implications. First, policymakers should take into account the empirical evidence of non-stationarity from the 1950s because this means that nowadays the levels of CO_2 emissions are uncontrolled. Additionally, the evidence of convergence for some countries with the U.S. is very worrying, as the U.S. is the major per capita polluting country.

Second, divergence among some countries implies that some of the developed countries are steadily increasing their levels of CO_2 emissions. This will discourage developing countries from constraining their emissions on the basis of certain notions of equality and responsibility, expect that developed countries, which are the main contributors to the atmospheric concentration of pollution, should make a greater effort to prevent climate change. Furthermore, the fact that industrialized countries are not able to follow a stable path of emission levels is not a good sign.

Additionally most rights distribution schemes are based on emissions per capita assuming country income convergence. However, analyzing convergence could lead to unfair distribution, as the results show that the CO_2 emissions series could be I(0) depending on the span considered. Thus, the assumption of convergence may entail an important transfer of wealth as Aldy (2006) argues in his research.

Finally, many climate models are designed assuming convergence across countries. Policymakers may use these models to assign quantitative emissions allocations across countries, since climate models produce precise numerical targets for emissions that should not be exceeded. Similarly, the success of tools such as the Kyoto protocol, also rely on these models. These issues show the importance of taking into account the empirical evidence in the design of climate models. Therefore, this paper aims to understand CO_2 emissions behavior, shedding light as a result on these controversial turning points.

2.7 ANNEXES

Table 8: Linear Tests 1870-2006

1870	MZ_t^{GLS}	LAG	**L(1)**	**TIME**	**L(1) S(1)**	**TIME**	**L(2)**	**TIME**	**L(2) S(2)**	**TIME**
AUS	-0.6	1	-1.41	1899	-3.47	1904	-1.55	1899 1931	-4.33	1913 1937
AUSL	-2.43	4	-4.04**	1916	-3.99	1915	-4.27**	1916 1929	-6.16**	1914 1948
BEL	-3.02**	2	-4.45***	1982	-4.65**	1982	-4.65***	1950 1982	-5.32*	1939 1970
CA	-0.4	3	-0.82	1887	-3.55	1904	-0.88	1887 1922	-4.87	1883 1905
DEN	-0.63	2	-2.32	1991	-3.33	1981	-2.58	1895 1991	-5.56*	1915 1965
FIN	-3.3**	1	-3.46*	1945	-4.07	1965	-3.71*	1926 1947	-4.71	1912 1925
FR	-1.53	2	-2.92	1980	-3.57	1984	-3.04	1980 1993	-5.09	1939 1973
GER	-1.71	2	-3.13	1906	-3.88	1894	-3.25	1887 1906	-5.23	1912 1954
GRE	-2.67	1	-3.10	1949	-3.72	1949	-3.20	1908 1949	-4.66	1937 1949
IT	-1.94	6	-4.78***	1946	-5.03**	1946	-5.19***	1916 1946	-6.39***	1941 1963
JA	-0.72	6	-1.36	1893	-3.98	1888	-1.39	1893 1920	-4.77	1883 1898
NETH	-2.95*	2	-4.33***	1969	-4.49**	1959	-4.4205**	1969 1991	-6.51***	1939 1970
NZ	-1.33	3	-1.65	1950	-3.45	1920	-1.8318	1913 1950	-4.74	1913 1938
NOR	-1.28	7	-3.53*	1939	-3.78	1920	-3.7874*	1939 1989	-4.89	1914 1966
POR	-2.3	5	-1.63	1917	-3.80	1883	-1.7001	1917 1937	-5.63**	1883 1941
SP	-2.06	2	-3.1527	1916	-3.87	1932	-3.4545	1916 1932	-5.67**	1932 1972
SWE	-1.22	6	-2.7859	1979	-3.62	1982	-2.9347	1898 1979	-4.85	1915 1969
SWI	-1.45	6	-2.9624	1920	-3.43	1920	-3.2042	1893 1920	-4.60	1915 1962
UK	-0.63	4	-4.35***	1979	-5.58***	1981	-5.1215***	1893 1979	-8.92***	1918 1971
USA	-0.94	11	-1.45	1887	-3.74	1902	-1.598	1887 1906	-4.52	1917 1940
$\overline{CO}_{2t}$	-1.63	1	-2.24	1920	-2.97	1916	-2.4528	1920 1944	-3.75	1915 1962
TOTAL I(0)	**3/21**		**7/21**		**4/21**		**7/21**		**8/21**	

Notes: ** and *** denote rejects the null at the 5% and 1% respectively. "L" and "S" means that break occurs in the level and in the slope respectively. In brackets the numbers of changes is indicated. Lee and Strazicich tests are computed using the general to specific approach to determine the value of "k". The set of critical values for linear tests are summarized in Table . They are extracted from Ng and Perron (2001) and Lee and Strazicich (2003).

Table 9: Linear Tests 1900-2006

1900	MZ_t^{GLS}	LAG	L(1)	TIME	L(1) S(1)	TIME	L(2)	TIME	L(2) S(2)	TIME
AUS	-2.48	1	-2.52	1931	-2.50	1961	-2.79	1931 1953	-4.17	1929 1980
AUSL	-2.04	4	-3.46*	1915	-4.57**	1945	-3.70*	1915 1947	-5.52*	1914 1948
BEL	-2.81*	2	-3.88**	1950	-4.16	1967	-4.05**	1926 1950	-4.52	1939 1970
CA	-1.97	2	-2.30	1912	-3.16	1921	-2.35	1912 1934	-4.08	1923 1969
DEN	-1.4	2	-2.62	1996	-3.76	1965	-2.88	1959 1996	-5.2504	1957 1969
FIN	-2.78*	1	-3.09	1945	-3.75	1921	-3.36	1919 1945	-4.41	1912 1923
FR	-2.01	2	-2.63	1948	-3.22	1966	-2.76	1948 1996	-4.03	1939 1973
GER	-2.86*	2	-3.60**	1949	-4.18*	1950	-3.78*	1949 1959	-5.13	1949 1975
GRE	-2.71	1	-3.06	1949	-3.58	1949	-3.13	1918 1949	-4.62	1937 1949
IT	-1.77	6	-4.53***	1946	-5.21***	1946	-5.03***	1935 1946	-7***	1946 1970
JA	-2.04	3	-2.50	1948	-2.58	1960	-2.71	1948 1960	-4.78	1943 1970
NETH	-2.82*	2	-3.71**	1969	-4.42*	1961	-3.88**	1959 1969	-5.87**	1939 1970
NZ	-2.1	3	-2.28	1912	-3.30	1932	-2.47	1912 1951	-4.76	1917 1950
NOR	-1.92	8	-3.63**	1969	-3.98	1959	-3.88**	1937 1969	-5.26	1939 1970
POR	-1.08	5	-2.04	1917	-3.83	1944	-2.23	1917 1937	-4.38	1915 1961
SP	-1.7	2	-2.78	1969	-4.11	1938	-3.03	1916 1969	-6.76***	1934 1972
SWE	-1.83	3	-2.84	1945	-3.60	1965	-2.91	1917 1945	-4.43	1940 1969
SWI	-2.16	2	-2.92	1920	-3.66	1953	-3.22	1920 1955	-5.55*	1941 1968
UK	-1.17	6	-5.08***	1950	-5.84***	1950	-6.14***	1950 1979	-8.05***	1918 1971
USA	-1.77	12	-2.73	1912	-3.1	1921	-2.92	1923 1981	-4.27	1919 1940
$\overline{CO}_{2t}$	-2.3	1	-2.43	1916	-3.06	1949	-2.61	1916 1947	-4.66	1941 1970
	MZ_t^{GLS}		L(1)		L(1) S(1)		L(2)		L(2) S(2)	
TOTAL I(0)	4/21		7/21		5/21		7/21		6/21	

Notes: ** and *** denote rejects the null at the 5% and 1% respectively. "L" and "S" means that break occurs in the level and in the slope respectively. In brackets the numbers of changes is indicated. The set of critical values for linear tests are summarized in Table 11. They are extracted from Ng and Perron (2001) and Lee and Strazicich (2003). Greece data starts at 1983 and New Zealand at 1878. Turkey data starts at 1923 and Ireland at 1924.

Table 10: Linear Tests 1950-2006

1950	MZ_t^{GLS}	LAG	**L(1)**	**TIME**	**L(1) S(1)**	**TIME**	**L(2)**	**TIME**	**L(2) S(2)**	**TIME**
AUS	-0.42	1	-1.2579	1998	-3.23	1978	-1.54	1931 1953	-4.45	1929 1980
AUSL	-0.83	1	-1.3662	1979	-4.52**	1976	-1.63	1932 1953	-5.79**	1930 1980
BEL	-1.14	1	-1.7137	1982	-3.14	1970	-2.06	1933 1953	-4.71	1931 1980
CA	-1.39	1	-1.4828	1969	-2.88	1969	-1.77	1934 1953	-3.86	1932 1980
DEN	-0.91	1	-1.6309	1991	-3.59	1969	-1.92	1935 1953	-4.40	1933 1980
FIN	-0.65	1	-1.1528	1958	-4.78**	1972	-1.38	1936 1953	-5.38*	1934 1980
FR	-0.61	1	-1.0019	1975	-3.62	1976	-1.18	1937 1953	-5.67**	1935 1980
GER	-0.24	1	-0.5862	1975	-2.37	1976	-0.70	1938 1953	-4.16	1936 1980
GRE	-0.78	4	-0.8065	1970	-3.57	1973	-0.86	1939 1953	-6.12**	1937 1980
IR	-1.21	1	-2.315	1958	-4.48**	1967	-2.80	1940 1953	-5.38*	1938 1980
IT	-0.83	2	-0.7621	1975	-4.16	1970	-0.90	1941 1953	-5.19	1939 1980
JA	-0.42	1	-0.7692	1975	-4.11	1969	-0.95	1942 1953	-4.44	1940 1980
NETH	-0.77	1	-1.3841	1969	-3.68	1970	-1.54	1943 1953	-4.18	1941 1980
NZ	-2.78	1	-2.7605	1983	-3.38	1985	-2.94	1944 1953	-4.44	1942 1980
NOR	-1.04	1	-1.8348	1989	-2.97	1968	-2.29	1945 1953	-4.04	1943 1980
POR	-1.04	1	-1.7152	1999	-2.71	1967	-1.84	1946 1953	-4.21	1944 1980
SP	-0.95	1	-1.5525	1969	-2.30	1980	-1.76	1947 1953	-4.20	1945 1980
SWE	-0.71	2	-0.7281	1959	-2.90	1969	-0.81	1948 1953	-5.66**	1946 1980
SWI	-0.25	1	-0.8012	1959	-6.39***	1970	-0.87	1949 1953	-7.47***	1947 1980
TUR	-1.14	1	-1.6917	1961	-2.94	1972	-2.04	1950 1953	-3.87	1948 1980
UK	-1.67	1	-1.7996	1979	-3.72	1972	-2.23	1951 1953	-4.23	1949 1980
USA	-1.61	1	-1.7737	1975	-2.98	1968	-1.87	1952 1953	-4.49	1950 1980
$\overline{CO}_{2t}$	-0.67	2	-0.8413	1975	-4.23*	1970	-0.99	1953 1953	-5.03	1951 1980
	MZ_t		**L(1)**		**L(1) S(1)**		**L(2)**		**L(2) S(2)**	
TOTAL I(0)	**0/23**		**0/23**		**5/23**		**0/23**		**7/23**	

Notes: ** and *** denote rejects the null at the 5% and 1% respectively. "L" and "S" means that break occurs in the level and in the slope respectively. In brackets the numbers of changes is indicated. The set of critical values for linear tests are summarized in Table 11. They are extracted from Ng and Perron (2001) and Lee and Strazicich (2003).

Table 11: Critical Values Linear Tests

The 5 and 10% asymptotic null critical values for the MZ_t^{GLS} test with both trend and an intercept term are, in that order, -23.8, -17.3 and -3.42, -2.91 respectively. Meanwhile the critical values for the **?** tests for the case that breaks occur only in level the values critics are -4.24, -3.57 and -4.54, -3.84 for 1 and 2 breaks respectively. Finally if breaks occur simultaneously in level and slope the following are the critical values to consider:

L(1)S(1)		
λ	1%	5%
0.1	-5.11	-4.50
0.2	-5.07	-4.47
0.3	-5.15	-4.45
0.4	-5.05	-4.50
0.5	-5.11	-4.51

L(2)S(2)						
	λ_2					
	0.4		0.6		0.8	
λ_1	1%	5%	1%	5%	1%	5%
0.2	-6.16	5.59	-6.41	- 5.74	-6.33	-5.71
0.4			-6.45	5.67	-6.42	-5.65
0.6					-6.32	-5.73

λ_j denotes the location of breaks. 1 and 5 % are the levels of statistical significance.

Table 12: Time of the Breaks

SPAN	1870-2006				1900-2006				1950-2006			
Periods	**L(1)**	**S(1)**	**L(2)**	**L(2) S(2)**	**L(1)**	**S(1)**	**L(2)**	**L(2) S(2)**	**L(1)**	**S(1)**	**L(2)**	**L(2) S(2)**
1870-1900	4	3	8	4	-	-	-	-	-	-	-	-
1900-1925	6	8	12	12	7	3	11	0	-	-	-	-
1925-1950	4	3	11	14	8	7	15	6	-	-	-	-
1950-1970	2	2	4	7	5	11	12	17	8	8	21	15
1970-1990	4	5	5	5	0	0	2	7	12	15	15	28
1990-2006	1	0	2	0	1	0	2	12	3	0	10	3

Table 13: Non Linear Test KSS 1870-2006

COUNT.	AIC	LAG	BIC	LAG	HQ	LAG	MAIC	LAG	COUNT.	AIC	LAG	BIC	LAG	HQ	LAG	MAIC	LAG
AUS	-1.39	4	-1.98	0	-1.98	0	-1.07	3	**JA**	-0.5	4	-0.5	4	-0.5	4	-0.5	4
AUSL	-5.45***	2	-5.45***	2	-5.45***	2	-4.18***	0	**NETH**	-2.17	2	-2.45	0	-2.45	0	-2.17	2
BEL	-2.04	2	-2.41	0	-2.41	0	-2.04	2	**NZ**	-4.78***	0	-4.78***	0	-4.78***	0	-4.78***	0
CA	-2.64*	4	-2.31	0	-2.31	0	-1.23	1	**NOR**	-2.24	3	-1.37	0	-1.37	0	-1.37	0
DEN	-0.79	2	-0.79	2	-0.79	2	-0.79	2	**POR**	-3.33**	4	-2.97**	3	-3.33**	4	-2.97**	3
FIN	-2.56	0	-2.56	0	-2.56	0	-2.56	0	**SP**	-2.23	2	-2.23	2	-2.23	2	-2.23	2
FR	-1.48	0	-1.48	0	-1.48	0	-1.05	2	**SWE**	-1.88	1	-1.88	1	-1.88	1	-1.88	1
GER	-1.37	1	-1.37	1	-1.37	1	-0.94	4	**SWI**	-3.48***	4	-3.77***	0	-3.77***	0	-3.01**	2
GRE	-2.96**	0	-2.96**	0	-2.96**	0	-2.96**	0	**USA**	-2.97**	2	-3.44**	0	-3.44**	0	-2.97**	2
IT	-3.41**	4	-3.06**	3	-3.06**	3	-2.89**	0	$\overline{CO}_{2t}$	-2.85*	0	-2.85*	0	-2.85*	0	-2.85*	0
CRITERIA	**AIC**		**BIC**		**HQ**		**MAIC**										
TOTAL I(0)	**9/20**		**8/20**		**8/20**		**8/20**										

All the countries are tested accommodating trend. The finite-sample critical values are obtained through Monte Carlo simulations with 50,000 replications. ***, ** and * imply rejection of the null hypothesis at 1%, 5% and 10%, respectively. They are -3.47, -2.87 and -2.58 for 1870-2006 span, while -3.47 -2.87 and -2.56 from 1900 to 2006. The test has been computed including a constant and a time trend as deterministic component. New Zealand data starts at 1878. Turkey data starts at 1923 and Ireland at 1924.

Table 14: Non Linear Test KSS 1900-2006

COUNT.	AIC	LAG	BIC	LAG	HQ	LAG	MAIC	LAG	COUNT.	AIC	LAG	BIC	LAG	HQ	LAG	MAIC	LAG
AUS	-1.18	1	-0.94	0	-0.94	0	-0.94	0	**NETH**	-2.37	0	-2.37	0	-2.37	0	-2.11	2
AUSL	-6.36***	2	-6.36***	2	-6.36***	2	-4.34***	0	**NZ**	-1.41	0	-1.41	0	-1.41	0	-1.41	0
BEL	-1.79	2	-2.13	0	-2.13	0	-1.79	2	**NOR**	-4.67***	0	-4.67***	0	-4.67***	0	-4.67***	0
CA	-1.87	0	-1.87	0	-1.87	0	-1.58	2	**POR**	-3.96***	3	-3.29**	0	-3.29**	0	-3.29**	0
DEN	-1.3	2	-1.86	0	-1.3	2	-1.3	2	**SP**	-5***	1	-5***	1	-5***	1	-4.08***	0
FIN	-2.52	0	-2.52	0	-2.52	0	-2.52	0	**SWE**	-5.93***	0	-5.93***	0	-5.93***	0	-5.93***	0
FR	-1.07	0	-1.07	0	-1.07	0	-1.07	0	**SWI**	-6.82***	4	-6.59***	0	-6.59***	0	-6.59***	0
GER	-1.25	1	-1.25	1	-1.25	1	-1.08	2	**UK**	-0.39	4	-0.39	4	-0.39	4	-0.39	4
GRE	-3.08**	0	-3.08**	0	-3.08**	0	-3.08**	0	**USA**	-3.38**	0	-3.38**	0	-3.38**	0	-2.58*	2
IT	-5.53***	1	-5.53***	1	-5.53***	1	-3.41**	0	$\overline{CO}_{2t}$	-4.8***	1	-4.25***	0	-4.8***	1	-4.25***	0
JA	-2.77*	3	-2.77*	3	-2.77*	3	-2.45	2									
CRITERIA	**AIC**		**BIC**		**HQ**		**MAIC**										
TOTAL I(0)	**11/21**		**11/21**		**11/21**		**10/21**										

All the countries are tested accommodating trend. The finite-sample critical values are obtained through Monte Carlo simulations with 50,000 replications. ***, ** and * imply rejection of the null hypothesis at 1%, 5% and 10%, respectively. They are -3.47, -2.87 and -2.58 for 1870-2006 span, while -3.47 -2.87 and -2.56 from 1900 to 2006. The test has been computed including a constant and a time trend as deterministic component. New Zealand data starts at 1878. Turkey data starts at 1923 and Ireland at 1924.

Table 15: Non Linear KSS Test 1950-2006

COUNTRY	AIC	LAG	BIC	LAG	HQ	LAG	MAIC	LAG	COUNTRY	AIC	LAG	BIC	LAG	HQ	LAG	MAIC	LAG
AUS	-1.97	4	-2.65*	0	-2.65*	0	-1.63	3	NETH	-1.99	0	-1.99	0	-1.99	0	-1.99	0
AUSL	-3.06**	0	-3.06**	0	-3.06**	0	-2.78*	2	NZ	-1.93	3	-2.11	0	-1.93	3	-1.79	1
BEL	-1.91	2	-1.58	1	-1.91	2	-1.58	1	NOR	-4.6***	0	-4.6***	0	-4.6***	0	-3.7***	1
CA	-1.44	0	-1.44	0	-1.44	0	-1.44	0	POR	1.29	1	1.25	0	1.29	1	0.86	2
DEN	-2.48*	0	-2.48*	0	-2.48*	0	-1.94	4	SP	0.35	0	0.35	0	0.35	0	0.35	0
FIN	-4.27***	0	-4.27***	0	-4.27***	0	-3.72***	2	SWE	-1.76	1	-1.98	0	-1.98	0	-1.76	1
FR	-1.73	0	-1.73	0	-1.73	0	-1.47	1	SWI	-3.94***	4	-3.94***	4	-3.94***	4	-2.22	1
GER	-2.89**	0	-2.89**	0	-2.89**	0	-2.27	1	TUR	-0.07	0	-0.07	0	-0.07	0	-0.07	0
GRE	1.71	0	1.71	0	1.71	0	1.71	0	UK	-3.64***	0	-3.64***	0	-3.64***	0	-2.67*	1
IR	-0.12	4	-1.14	0	-1.2	1	-0.12	4	USA	-2.2	4	-1.24	0	-2.2	4	-1.24	0
IT	-1.71	2	-1.71	2	-1.71	2	-0.15	1	$\overline{CO}_{2t}$	-3.63***	2	-3.77***	1	-3.77***	1	-3.64***	0
JA	-3.59***	4	-3.59***	4	-3.59***	4	-2.19	0									
CRITERIA	**AIC**		**BIC**		**HQ**		**MAIC**										
TOTAL I(0)	9/23		10/23		10/23		5/23										

Notes: Critical values at the 1%, 5% and 10% are -3.44, -2.79 and -2.47 at the 1%, 5% and 10% respectively for the sub-period between 1950 to 2006. The test has been computed including a constant and a time trend as deterministic component.

Table 16: Convergence via Carlino and Mills' Measure 1870-2006

CONT.	AIC	K	BIC	K	HQ	K	MAIC	K	CONT.	AIC	K	BIC	K	HQ	K	MAIC	K
AUS	-3.02**	4	-2.78*	0	-3.05**	3	-2.58*	2	JA	-0.93	4	-0.93	4	-0.93	4	-0.93	4
AUSL	-4.91***	4	-5.07***	1	-4.91***	4	-4.1***	0	NETH	-1.64	4	-1.64	4	-1.64	4	-1.64	4
BEL	-4.01***	3	-3.81***	1	-3.81***	1	-3.61***	0	NZ	-5.13***	4	-3.21**	0	-5.13***	4	-3.21**	0
CA	-3.37**	4	-2.46	0	-3.22**	3	-2.49	1	NOR	-4.16***	4	-5.17***	0	-5.17***	0	-3.76***	3
DEN	-1.69	2	-1.98	0	-1.69	2	-1.69	2	POR	-3.08**	3	-3.08**	3	-3.08**	3	-3.08**	3
FIN	-3.23**	0	-3.23**	0	-3.23**	0	-2.48	2	SP	-5.69***	1	-5.69***	1	-5.69***	1	-4.89***	0
FR	-3.14**	3	-2.5	1	-2.5	1	-2.5	1	SWE	-3.49***	1	-4.37***	0	-4.37***	0	-2.66*	3
GER	-5.14***	4	-5.17***	0	-5.14***	4	-4.79***	1	SWI	-6.81***	0	-6.81***	0	-6.81***	0	-6.81***	0
GRE	-3.4**	0	-3.4**	0	-3.4**	0	-3.4**	0	UK	-2.67*	0	-2.67*	0	-2.67*	0	-2.67*	0
IT	-5.41***	1	-5.41***	1	-5.41***	1	-3.8***	0	USA	-2.73*	0	-2.73*	0	-2.73*	0	-2.73*	0
CRITERIA	**AIC**		**BIC**		**HQ**		**MAIC**										
TOTAL I(0)	17/20		15/20		16/20		13/20										

All the countries are tested accommodating trend. The finite-sample critical values are obtained through Monte Carlo simulations with 50,000 replications. ***, ** and * imply rejection of the null hypothesis at 1%, 5% and 10%, respectively. They are -3.47, -2.87 and -2.58 for 1870-2006 span, while -3.44, -2.79 and -2.47 from 1950 to 2006.

Table 17: Convergence via Carlino and Mills' Measure 1950-2006

CONT.	AIC	K	BIC	K	HQ	K	MAIC	K	CONT.	AIC	K	BIC	K	HQ	K	MAIC	K
AUS	-2.04	0	-2.04	0	-2.04	0	-1.77	1	**JA**	-0.31	4	-0.75	0	-0.75	0	-0.31	4
AUSL	-4.17***	0	-4.17***	0	-4.17***	0	-2.86**	2	**NETH**	-3.5***	0	-3.5***	0	-3.5***	0	-3.5***	0
BEL	-0.53	1	-0.53	1	-0.53	1	-0.53	1	**NZ**	-2.67*	2	-2.67*	2	-2.67*	2	-2.03	1
CA	-2.41	2	-2.41	2	-2.41	2	-2.07	0	**NOR**	-5.22***	2	-6.07***	0	-6.07***	0	-4.76***	1
DEN	-1.96	0	-1.96	0	-1.96	0	-0.77	4	**POR**	0.52	1	0.52	1	0.52	1	0.3	3
FIN	-2.4	4	-2.62*	0	-2.4	4	-2.62*	0	**SP**	-1.43	2	-2.18	0	-1.43	2	-1.43	2
FR	-1.66	1	-1.66	1	-1.66	1	-1.66	1	**SWE**	-3.53***	0	-3.53***	0	-3.53***	0	-2.62*	1
GER	-0.57	2	-0.57	2	-0.57	2	-0.57	2	**SWI**	-3.49***	4	-3.49***	4	-3.49***	4	-2.12	1
GRE	1.41	4	0.79	0	1.08	1	0.79	0	**TUR**	-1.84	3	-2.5	0	-2.5	0	-1.79	2
IR	-2.55*	1	-2.55*	1	-2.55*	1	-1.44	4	**UK**	-0.41	4	1.61	0	1.61	0	-0.41	4
IT	-2.21	0	-2.21	0	-2.21	0	-2.21	0	**USA**	-1.6	4	-1.6	4	-1.6	4	-1.54	1
CRITERIA	**AIC**		**BIC**		**HQ**		**MAIC**										
TOTAL I(0)	**7/22**		**9/22**		**8/22**		**5/22**										

All the countries are tested accommodating trend. The finite-sample critical values are obtained through Monte Carlo simulations with 50,000 replications. ***, ** and * imply rejection of the null hypothesis at 1%, 5% and 10%, respectively. They are -3.47, -2.87 and -2.58 for 1870-2006 span, while -3.44, -2.79 and -2.47 from 1950 to 2006.

Table 18: Convergence versus The US 1870-2006

1870									1950							
COUNT.	**AIC**	**K**	**BIC**	**K**	**HQ**	**K**	**MAIC**	**K**	**COUNT.**	**AIC**	**K**	**BIC**	**K**	**HQ**	**K**	**MAIC**	**K**
AUS	-2.58	2	-2.58*	2	-2.58*	2	-2.58*	2	**JA**	-2.47	4	-2.47	4	-2.47	4	-2.47	4
AUSL	-4.18***	2	-3.7***	1	-4.18***	2	-3.15**	0	**NETH**	-4.94***	0	-4.94***	0	-4.94***	0	-4.94***	0
BEL	-4.25***	0	-4.25***	0	-4.25***	0	-4.25***	0	**NZ**	-2.55	0	-2.55	0	-2.55	0	-2.24	2
CA	-3.85***	4	-3.14**	3	-3.85***	4	-2.08	2	**NOR**	-3.96***	0	-3.96***	0	-3.96***	0	-3.96***	0
DEN	-2.8*	3	-4.25***	0	-4.25***	0	-2.59*	2	**POR**	-3.04**	3	-3.04**	3	-3.04**	3	-2.51	2
FIN	-3.28**	0	-3.28**	0	-3.28**	0	-3.28**	0	**SP**	-2.6*	2	-4.02***	0	-4.02***	0	-2.07	4
FR	-3.38**	0	-3.38**	0	-3.38**	0	-3.38**	0	**SWE**	-5.78***	0	-5.78***	0	-5.78***	0	-5.78***	0
GER	-6.1***	0	-6.1***	0	-6.1***	0	-3.9***	2	**SWI**	-5.22***	0	-5.22***	0	-5.22***	0	-5.22***	0
GRE	-2.99**	0	-2.99**	0	-2.99**	0	-2.99**	0	**UK**	-1.51	2	-1.51	2	-1.51	2	-1.51	2
IT	-5.05***	1	-5.05***	1	-5.05***	1	-3.62***	0									
CRITERIA	**AIC**		**BIC**		**HQ**		**MAIC**										
TOTAL I(0)	**16/19**		**16/19**		**16/19**		**13/19**										

All the countries are tested accommodating trend. The finite-sample critical values are obtained through Monte Carlo simulations with 50,000 replications. ***, ** and * imply rejection of the null hypothesis at 1%, 5% and 10%, respectively. They are -3.47, -2.87 and -2.58 for 1870-2006 span, while -3.44, -2.79 and -2.47 from 1950 to 2006.

Table 19: Convergence versus The US 1950-2006

COUNT.	AIC	K	BIC	K	HQ	K	MAIC	K	COUNT.	AIC	K	BIC	K	HQ	K	MAIC	K
AUS	-0.15	4	-1.66	0	-1.66	0	-0.15	4	**JA**	-1.05	0	-1.05	0	-1.05	0	-0.45	1
AUSL	-2.7*	4	-3.89***	3	-3.89***	3	-2.73*	0	**NETH**	-1.11	0	-1.11	0	-1.11	0	-0.34	4
BEL	-4.69***	0	-4.69***	0	-4.69***	0	-3.25**	1	**NZ**	-2.1	4	-2.5	0	-2.2	2	-1.89	1
CA	-1.53	1	-2.31	0	-2.31	0	-1.36	2	**NOR**	-0.99	1	-0.99	1	-0.99	1	-0.79	2
DEN	-1.58	1	-1.59	0	-1.59	0	-0.8	4	**POR**	0.71	1	0.71	1	0.71	1	0.56	0
FIN	-1.09	4	-1.65	3	-1.09	4	-1.09	4	**SP**	-0.75	2	-1.25	0	-0.75	2	-0.75	2
FR	-2.37	4	-2.94**	0	-2.94**	0	-2.3	1	**SWE**	-3.39**	3	-3.39**	3	-3.39**	3	-2.61*	1
GER	-4.04***	0	-4.04***	0	-4.04***	0	-2	4	**SWI**	-3.22**	4	-3.22**	4	-3.22**	4	-1.63	1
GRE	0.93	1	0.93	1	0.93	1	0.36	4	**TUR**	-1.37	0	-1.37	0	-1.37	0	0.05	3
IR	-1.39	3	-2.74*	0	-1.39	3	-1.39	3	**UK**	-2.55*	4	-3.67***	0	-2.55*	4	-2.67*	2
IT	-1.83	4	-2.87**	0	-2.87**	0	-2.22	1									

CRITERIA	**AIC**	**BIC**	**HQ**	**MAIC**
TOTAL I(0)	**6/21**	**10/21**	**8/21**	**4/21**

All the countries are tested accommodating trend. The finite-sample critical values are obtained through Monte Carlo simulations with 50,000 replications. ***, ** and * imply rejection of the null hypothesis at 1%, 5% and 10%, respectively. They are -3.47, -2.87 and -2.58 for 1870-2006 span, while -3.44, -2.79 and -2.47 from 1950 to 2006.

3

COULD ENVIRONMENTAL POLICIES BE ENFORCED WITHOUT AFFECTING ECONOMIC GROWTH?

3.1 INTRODUCTION

Achieving sustainable development is important for understanding the highly complex relationship that exists between economic growth and environmental degradation. The fact that most economic activities require energy has been a cause of concern due to the close link that exists between energy consumption and its negative effects on the environment. There is a wide consensus about the necessity of reducing the current level of emissions. However, there is also a risk of seriously dampening economic growth, especially in the case of emerging economies.

Developing countries are, today, those that release the greatest amount of CO_2. However, the richer industrialised nations are responsible for the majority of the environmental damage caused to date. Therefore, if energy acts as a limiting factor for economic growth (as is often claimed by emerging countries), it would be unfair to ask them to attain the same target that should be imposed on developed countries because the future growth of these emerging countries could be critically affected.

Accordingly, environmental policies have become a matter of concern not only for scientists but also for economists, as the efforts to prevent climate change may reduce economic growth. This troubling trade-off between emissions limitations and economic development has led to an extensive empirical literature that, for expositive reasons, can be split into three main lines of research.

The first strand of the empirical literature is based on the concept of an environmental Kuznets curve (EKC), which posits that a country's economic development has a positive effect on the environment given that when a country reaches a certain critical level of development, it can afford and would 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 energy, 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 have aimed to validate the EKC hypothesis, it remains empirically open.

A second strand of the literature focuses on determining - using primarily the methodology proposed by Granger (1987) - whether there is a significant causal relationship between energy consumption (EC hereafter) and growth (usually proxied by GDP) and analysing and interpreting the direction of the relationship. As explained in Ozturk (2010), four main hypotheses can be tested, each having different policy implications. First, the absence of a relationship between EC and GDP is referred to as the neutrality hypothesis. When energy is a neutral input in economic development, economic growth is not at risk due to preservation policies.

Second, when there is unidirectional causality running from energy consumption to GDP, conservation policies will adversely affect economic development. This is known as the growth hypothesis.

The conservation hypothesis states the opposite. That is, if economic growth causes energy consumption, policies involving environmental preservation may have little effect on economic development.

Finally, bi-directional causality between energy consumption and economic growth would suggest that both are complementary. This should be considered when modelling the relationship as both variables would have to be considered endogenous. This is called the feedback hypothesis.

Chontanawat et al. (2008), Hu and Lin (2008), and Ozturk (2010) showed that the causal relationship between energy consumption and growth is empirically ambiguous and controversial. In a survey, Huang et al. (2008, Table 1) showed discrepancies among the studies, even for cases in which the countries in the sample were identical. These authors argued that much of the heterogeneity in the results is due to the different methodologies applied. Ozturk (2010) reported similar findings.

Furthermore, Zachariadis (2007) noted two additional sources of ambiguity. First, the aggregation level of both EC and GDP may be too high. Second, due to the importance of the causality channels linking the variables involved in the analysis, the bivariate relationship may act as a trigger of the empirical discrepancy because the effects of other variables may be masked under a bivariate examination.

However, Péguin-Feissolle et al. (2007) argued that the problem could be the functional linear form specified to link the two variables rather than the number of variables analysed. These authors further noted that the Granger linear causality test has a minimal ability to detect certain forms of nonlinear causality.

In the EC-GDP nexus literature, most of the authors test the abovementioned hypotheses using linear methodologies. However, as noted by **?**, among others, this methodology does not consider the potential nonlinearities of GDP and EC. If these series exhibit nonlinear behaviour, the standard tests, i.e., the linear methodology, may suffer from power problems. In other words, they tend to over-accept the null hypothesis.

Therefore, in this paper, consistent with Bradford et al. (2000), Mäuller-Fäurstenberger and Wagner (2007), Wagner (2008), and Hong and Wagner (2008), we analyse the importance of accounting for the nonlinearities in the study of causality between GDP and CO_2 emissions. We use CO_2 emissions as a proxy of energy consumption because the span available of these series is longer than that for EC, for which the number of observations is critical to capture a potential nonlinear pattern.

Because evidence of cointegration ensures causality in at least one direction, a crucial previous step to the study of causality is a first analysis of the stationarity of CO_2 emissions and GDP ratio. To study the nature of the series, a standard unit root test is used, and we match the results against those obtained by applying a test that accounts for nonlinearities, as proposed by Kruse (2011). Then, based on these results, we apply the most suitable methodology to study the causality between the two series.

The paper is organised as follows. In the next section, we discuss the main arguments that justify the use of nonlinear techniques for studying CO_2 emissions and GDP. The third section describes the data and the empirical methodology applied, and the last two sections provide the empirical results and the conclusions, respectively.

3.2 CONTRIBUTION

In this paper, we attempt to discern whether CO_2 emissions (used here as a proxy for EC) are a critical input for GDP growth. For this purpose, we apply a two-step methodology to ensure that we choose the most suitable functional form in the study of causality between CO_2 and GDP.

The assumption in a number of previous studies is that the CO_2-GDP relationship is linear; however, there are several arguments against the assumption of linearity, as discussed below.

-Energy prices causing different* CO_2 *regimes

Historical events suggest that a significant and persistent increase in energy prices over time is usually followed by a downward adjustment of gross domestic output (Barassi and Spagnolo, 2012). However, this adjustment is not instantaneous because a delay exists between the increase in prices and the decline in the level of production. After a transitory period, this economic contraction causes a reduced level of emissions, which will predictably be maintained until energy prices, especially oil prices, significantly vary again.

It is important to note that the nonlinear pattern of energy prices can be transferred to the CO_2-GDP ratio because energy prices may be behind some of the contractions and expansions experienced by GDP and, hence, behind different levels of emissions. Thus, the high volatility of energy prices makes the linear models an unsuitable framework for capturing the dynamics of this relationship.

If the relationship between CO_2 and GDP can be characterised as nonlinear with different regimes, transitions between them can be interpreted as non-stationary processes using standard (linear) tests, even when the variables are, in fact, nonlinear but globally stationary.

If the CO_2-GDP ratio has nonlinear dynamics and non-simultaneous adjustment, neglecting these features would lead to the erroneous conclusion that the CO_2-PIB relationship produces I(1) residuals, meaning that there is no cointegration between the variables. Choosing a test that allows nonlinear and asymmetric adjustment towards long-run equilibrium avoids spurious regressions and misinterpreting the order of integration of the CO2-GDP relationship.

- Pollution Haven Hypothesis and Porter Hypothesis

More stringent environmental regulations increase competitive pressure, especially in those firms operating in the most contaminated activities.

To adapt to regulations, companies may choose from several options. First, companies could buy emissions rights to continue releasing similar levels of CO_2; second, they can produce less, therefore limiting emissions; third (also called Porter Hypothesis), they can invest in clean and efficient technologies that enable them to adapt to regulations while simultaneously being more competitive; or fourth, they can relocate to countries with more lax environmental regulations. The last alternative is known as the pollution haven hypothesis (PHH), which states that companies in countries forced to comply with strict environmental regulations may eventually relocate to countries with weaker environmental laws.

According to the PHH, the emissions of countries subject to regulatory pressure may suffer a downturn in the amount of CO_2 released as a consequence of tightening environmental regulations. Nevertheless, it is unlikely that companies "migrate" suddenly in response to a new regulatory framework. Rather, one would expect to find a gradual change in the deterministic structure of the relationship.

Conversely, the Porter hypothesis states that compliance with strict environmental policies results in companies becoming more efficient and more innovative, thereby increasing their competitiveness. Changes in production functions will affect emissions levels. These structural changes are the result of progressive investment in clean and more efficient technologies. Therefore, models allowing for different regimes and smooth transitions seem more suitable than the linear methodology.

- Changes in sectoral specialisation

Changes in the deterministic structure of the GDP-CO_2 relationship can also be explained by the changes in the composition of the different sectors' contributions to GDP as a country grows. While in the early stages of industrialisation, sectors such as agriculture lose importance in favour of manufacturing; in more advanced stages of development, manufacturing and other consumer goods sectors are replaced by the less polluting services sector. This undoubtedly creates a structural change in the emissions that linear tests may be unable to capture.

- The environment as a luxury good

The environmental Kuznets curve (EKC) describes the time path that a country's emission level would follow as a result of its economic growth. In the early stages of industrialisation, pollution emissions grow sharply because the increase in production releases large amounts of emissions in countries that attach low priority to environmental degradation control. As countries reach a critical income level, their priorities switch to the protection of environmental quality, which would entail a regime change in CO_2 emissions levels.

To summarise, there are several reasons in favour of nonlinearities in the CO_2-GDP relationship.

Nevertheless, most studies analyse the CO_2-GDP ratio within a linear framework, which implies accepting two main assumptions. First, all of the changes discussed above occur instantaneously, i.e., the agents react simultaneously to an economic shock. Second, linear tests assume a unique mean value, and the process reverts to that value at a constant speed after a shock.

The limits related to these assumptions lead us to conclude that the most appropriate models to capture a possible cointegration relationship between CO2 and GDP are those that allow for multiple regimes and a smooth transition within those regimes. For the sake of comparison, we avoid the a priori exclusion of linear models by applying both linear and nonlinear tests.

3.3 EMPIRICAL STRATEGY AND DATA

In this paper, we study the causality relationship between CO_2 emissions and GDP. First, we analyse the stationarity of the CO_2-GDP ratio. Data on annual CO_2 emissions in metric tons were provided by the Carbon Dioxide Information Analysis Center (CDIAC, Boden et al. 2008), whereas data on GDP were obtained from the Penn World Table 6.3 (Heston et al. (2012)). Our sample consists of 10 countries (Belgium, Denmark, France, Germany, Netherlands, Norway, Spain, Sweden, the UK and the US) covering the period from 1850 to 2008. Both variables are measured in per capita terms using population data provided by Bolt and van Zanden (2013). The selection of countries is driven by the availability of data.

Nelson and Plosser (1982), Stock and Watson (1988) and Campbell (1992), among others, noted that most macroeconomic series present stochastic trends and unit roots. The use of conventional regression techniques assuming the stationarity of the time series would produce spurious regressions, and thus, the statistics may simply capture correlated trends rather than a true relationship (Granger and Newbold 1974).

We apply a conventional augmented Dickey–Fuller test to examine the stationarity of the ratio $y_t = CO_2emission/GDP$. The ADF test is based on the following specification:

$$\triangle y_t = \alpha + \beta t + \gamma y_{t-1} + \delta_1 \triangle y_{t-1} + ... + \delta_{p-1} \triangle y_{t-p+1} + \varepsilon_t \quad (12)$$

where ε_t is assumed to be white noise. Thus, the null hypothesis of unit root $H_0 : \alpha = 0$ against the alternative of a stationary process $H_1 : \alpha < 0$ can be tested using the conventional t-ratio.

However, as mentioned in Section 2, we should consider possible nonlinearities in the data-generating process of CO_2 and GDP. Therefore, to examine the stationarity of the variables, we should apply a nonlinear test. As stated by many authors, such as Kapetanios et al. (2003), if the CO_2-GDP relationship exhibits nonlinear dynamics, linear models tend to conclude that the combination of the two variables has a unit root, i.e., they are biased towards the hypothesis of non-stationarity.

Thus, Kapetanios et al. (2003) propose a unit root test against the alternative of a globally stationary exponential smooth transition autoregression (ESTAR).

$$y_t = \beta y_{t-1} + \phi y_{t-1} F(\theta; y_{t-1}) + \varepsilon_t \quad (13)$$

where ε_t is $iid\left(0, \sigma^2\right)$ and$F(\theta; y_{t-1})$ is the transition function, which is assumed to be exponential:

$$F(\theta; y_{t-1}) = 1 - \exp\left\{-\theta\left(y_{t-1} - c\right)^2\right\} \quad (14)$$

with $\theta > 0$. Kapetanios et al. 2003 assume that $c = 0$. It is common to implement the test to reparameterise equation (1) as:

$$\Delta y_t = \alpha y_{t-1} + \gamma y_{t-1}\left(1 - \exp\left\{-\theta y_{t-1}^2\right\}\right) + \varepsilon_t \tag{15}$$

The author imposes $\alpha = 0$, implying that the variable has a unit root in the central regime. The null hypothesis $H_0 : \theta = 0$ is tested against the alternative $H_1 : \theta > 0$, i.e., we test whether the variable is an I(1) process in the outer regime.

However, the assumption of Kapetanios et al. (2003) may be too restrictive for variables where the threshold value is different from 0. Thus, Kruse (2011) propose an extension of the Kapetanios unit root test, which relaxes the assumption of a zero location parameter c by considering the following modified ADF regression:

$$\Delta y_t = \alpha y_{t-1} + \gamma y_{t-1}\left(1 - \exp\left\{-\theta\left(y_{t-1} - c\right)^2\right\}\right) + \varepsilon_t \tag{16}$$

Following Kapetanios et al. 2003 it is possible to obtain a first-order Taylor approximation of equation (4)

$$\Delta y_t = \delta_1 y_{t-1}^3 + \delta_2 y_{t-1}^2 + \varepsilon_t \tag{17}$$

The null hypothesis of unit root is defined as $H_0 : \delta_1 = \delta_2 = 0$ against a globally stationary ESTAR process, $H_0 : \delta_1 \neq 0, \delta_2 < 0$. Kruse (2011) proposes a τ test, which is a version of the Abadir and Distaso (2007) Wald test.

Evidence of stationarity in the ratio, i.e., cointegration between the series, implies that Granger causality must exist in at least one direction between the variables. Therefore, the next methodological step is to apply a Granger causality test to determine which environmental hypothesis is confirmed. In a linear framework, the well-known Granger-causality test is applies, whereas if we find nonlinearities, we implement a causality test that considers nonlinearities. In particular, we apply the causality test proposed by Skalin and Teräsvirta (1999), which is based on the STAR model as follows:

$$y_t = S_t^{'}\Pi + S_t^{'}\theta F\left(z_t\right) + K\left(x_t\right) + \eta_t \tag{18}$$

where y_t and x_t are assumed to be stationary and ergodic. $S_t = \left(1, y_{t-1}, ..., y_{t-p}\right)^{'}$ is a $p+1$ vector of explanatory variables, $\Pi = \left(\pi_0, \pi_1, ..., \pi_p\right)^{'}$ and $\theta = \left(\theta_0, \theta_1, ..., \theta_p\right)^{'}$ are $p+1$ parameter vectors, and $F\left(z_t\right)$ is the transition function. Skalin and Teräsvirta (1999)noted that the simple STAR-based Granger causality equation can not be identified under the null hypothesis. To overcome this identification problem, they used the approximation of the second transition function $K\left(x_t\right)$ based on the its Taylor approximation. The third-order expansion, as in Luukkonen et al. (1988), is used to obtain the following model:

$$y_t = S_t^{'}\Pi + S_t^{'}\theta F\left(z_t\right) + \sum x_{t-j} + \sum\sum x_{t-j}x_{t-i} + \sum x_{t-j}^3 + \eta_t \tag{19}$$

The corresponding auxiliary regression used in testing the null hypothesis is:

$$\hat{\eta}_t = \beta_0^{'} g_t + \sum_{j=1}^{q} \delta_j x_{t-j} + \sum_{i=1}^{q}\sum_{j=1}^{q} \varphi_{ij} x_{t-i} x_{t-j} + \sum_{j=1}^{q} \psi_j x_{t-j}^3 \tag{20}$$

where $\hat{\eta}_t$ are independent, identically distributed estimated errors under H_0, g_t is the gradient vector of the parameters of the STAR model under H_0, and $\beta_0, \delta_j, \varphi_{ij}, \psi_j$ are $p+1$ parameter vectors. The hypothesis x_t does not Granger cause y_t, which can be written as $H_0 : \delta_j = 0, \varphi_{ij} = 0$ and $\psi_j = 0$, where $i, j = 1, ..., q$. The degrees of freedom of the approximating F-statistic are $q\,(q+1)\,/2 + 2q$ in the numerator and $T - n - q(q+1)/2 - 2q$ in the denominator, where T is the number of observations and n is the dimension of the gradient vector.

3.4 RESULTS

We report the results of linear methodology[1] in Table 1. In the second column, we present the t-statistics of the null hypothesis that the CO_2-GDP ratio contains a unit root.

Table 20: Linear Test Results

Country	t-test	Lag
BELGIUM	-1.0726	2
DENMARK	-1.1438	2
FRANCE (INCLUDING MONACO)	-2.4165	0
GERMANY	-2.1922	3
NETHERLANDS	-2.3465	0
NORWAY	-2.4749	1
SPAIN	-2.9761	0
SWEDEN	-2.4449	1
UNITED KINGDOM	-0.912	4
UNITED STATES OF AMERICA	-1.9495	1

Notes: The critical values for the ADF test at the 1%, 5%, and 10% significance levels are–-3.99, -3.43, and -3.13, respectively.

1 We use the "URADF" RATS code.

The hypothesis of a unit root can be easily rejected for all countries, thus suggesting that the CO_2-GDP ratios are non-stationary. This leads us to conclude that the CO_2 emissions and GDP do not maintain a long-term equilibrium, i.e., that the ratio between the two series is not stable because shocks are permanent rather than transitory.

We next check whether it is important to account for nonlinearities in the study of the relationship between CO2 and GDP. Accordingly, we consider the cointegration test developed by Kruse (2011), which tests the null hypothesis of no cointegration against an alternative of a globally stationary ESTAR cointegration.

Table 21: Nonlinear Test Results

Country	**t-test**
BELGIUM	5.38
DENMARK	16.78***
FRANCE (INCLUDING MONACO)	8.68*
GERMANY	10.95**
NETHERLANDS	5.36
NORWAY	8.63*
SPAIN	9.73*
SWEDEN	10.29**
UK	7.43
USA	17.24***

Notes: The critical values for the τ-test proposed by Kruse (2010) at the 1%, 5% and 10% significance levels are 13.75, 10.17, and 8.60, respectively.

The results reveal strong evidence in support of the stationarity of the ratio. For 7 of the 10 countries, we can reject the null of the unit root. With the exceptions of Belgium, the Netherlands, and the UK, the rest of the countries show a long-term equilibrium between CO_2 emissions and GDP. The two series thus move together, and the difference between them is stationary. Stationarity, i.e., evidence of cointegration for the ratio, implies that causality exists in at least one direction between CO_2 and GDP. However, it does not indicate the direction of the temporal causality between the variables. To determine the direction of causation, we must apply a Granger causality test.

Therefore, we analyse the direction of causality for the I(0)[2] ratios. Given that the variables CO_2 and GDP exhibit nonlinear dynamics, the standard linear Granger causality test is not appropriate for studying whether CO_2 (GDP) is a driving variable behind the path of GDP (CO_2). Accordingly, we apply the nonlinear causality test proposed by Skalind and Terasvirsta (1999), which is adapted to a STAR model. The second column of Table 3 shows the unidirectional Granger causality running from CO_2 emissions to GDP. We have found evidence of this direction of causality for all of the countries analysed. Thus, the growth hypothesis is confirmed by our data. With respect to the opposite direction, the results indicate that GDP causes CO_2 in 4 of the 7 countries. Finally, when taking all of the results together, we can conclude that there is clear evidence supporting bi-directional causality between energy consumption and economic growth. The existence of a long-term bi-directional causal relationship between CO_2 emissions and GDP has very important policy implications because a high GDP level leads to a high level of CO_2 emissions and vice versa. Therefore, for these countries, the interdependence between energy consumption and GDP suggests that energy policies

2 We cannot study by nonlinear methods the cases of Belgium, the Netherlands, or the UK because the Kruse (2011) ratios CO2-GDP are non-stationary and, therefore, tests for causality are not valid if cointegration does not exit.

that are designed to decrease energy use will have a negative impact on economic growth.

Table 22: Nonlinear Granger Causality

	CO_2 causes GDP				GDP causes CO_2				
Country	***p***	***d***	***q***	***P-VALUE***	***p***	***d***	***q***	***P-VALUE***	*Hypothesis*
DENMARK	1	3	1	2.68E-04***	2	3	1	0.03042**	***Feedback Hypothesis***
FRANCE (INCLUDING MONACO)	4	1	2	9.91E-12***	4	1	1	0.08667*	***Feedback Hypothesis***
GERMANY	2	1	1	2.99E-31***	1	2	1	0.00326***	***Feedback Hypothesis***
NORWAY	4	1	2	0.00944***	4	3	3	0.02945**	***Feedback Hypothesis***
SPAIN	1	3	1	0.02026**	3	1	1	0.0186**	***Feedback Hypothesis***
SWEDEN	1	4	1	0.0339**	4	1	1	0.04066**	***Feedback Hypothesis***
USA	2	4	1	0.05591**	1	3	4	2.56E-04***	***Feedback Hypothesis***

3.5 CONCLUSIONS AND POLICY IMPLICATIONS

We analyse the existence of causality between GDP and CO_2 emissions for 10 OECD countries from 1850 to 2008. In this paper, we argue that the linear methodology is not suitable in this case because it is not able capture the potential nonlinearities that could exhibit CO_2 emissions and GDP. However, for comparison reasons, we analyse the order of integration of the CO2-GDP ratio using a standard linear test. The results show that we cannot reject the unit root hypothesis in the ratio for any of the countries.

Conversely, when we apply a test that considers the nonlinear dynamics, we find different results. With the exception of Belgium, the Netherlands, and the UK, the CO_2-GDP ratio is stationary, thus providing evidence that causality exists for these countries in at least one direction.

Consequently, from the above findings a first important conclusion is that linear standard methodology cannot fully explore the dynamics between CO_2 and GDP.

The outcomes obtained from the Granger-causality nonlinear test validate the feedback hypothesis, i.e., a long-term bi-directional causal relationship between CO_2 emissions and GDP for all of the tested countries. Therefore, we conclude that the use of energy and the consequent release of emissions is a limiting factor to economic growth for these countries. With respect to policy implications, this means that energy conservation may hinder economic growth. On the contrary, those policies that improve the efficiency of the production and consumption of energy and the use of renewable energies may not have a detrimental impact on the GDP, but they may also enhance environmental quality because such policies will restrain excessive energy consumption and reduce inefficient energy production.

4 ENERGY USE-GDP DETERMINISTIC COINTEGRATION:PROGRESS TOWARD EU-15 KYOTO TARGETS

4.1 INTRODUCTION

The negotiations between the member states of the United Nations Framework Convention on Climate Change (UNFCCC) resulted in the Kyoto Protocol establishing binding emissions reduction targets for industrialized countries to reduce greenhouse gas (GHG) emissions. More specifically, EU-15 countries have the commitment period from 2008 to 2012 to reduce emissions to 8 percent lower than 1990 levels.

That commitment period is close to finished, so a new phase of negotiations has begun, but as was the case in the 90's, the search for a new international agreement to succeed the Kyoto Protocol is turning into a difficult task, as diverse positions exist regarding the best design for this new post-Kyoto agreement. However, prior to designing a new international regime to prevent climate change, a question arises: how much progress has been made in the fight to reduce emissions? This paper examines to what extent the long-run energy consumption-GDP relationship might reveal performance regarding the abatement targets established in the Kyoto Protocol. To this end we analyze whether energy consumption and GDP levels in EU-15 countries are in long run equilibrium. In contrast, if countries' output per capita displays an upward trend, but the level of energy use is not proportional, the hypothesis of a long-term relationship between energy consumption and GDP should be rejected, that is, there would be no cointegration. These countries will comply with Kyoto at a relatively lower cost than those whose growth and energy use trends share comovements over time, that is, when energy use and GDP are cointegrated.

Due to the significant impact that reducing energy use has on a country's development, this causal relationship has recently attracted widespread attention from researchers. However, as it can be seen in the complete surveys of Huang et al. (2008) and Payne (2010a), empirical results have been mixed.

This paper contributes to the empirical literature in two respects. First, we focus on the functional form as the most important reason behind the mixed findings. Camarero et al., (2011, Section 2) provide several arguments supporting that the relationship between energy use and GDP could be nonlinear. Second, we use the Chong et al. (2008) test to not only assess long-run co-movements between both variables caused by stochastic elements (*stochastic cointegration*), but also to analyze the deterministic trend (*deterministic cointegration),* which is a stronger concept of cointegration.

4.2 METHODOLOGY AND DATA TESTING FOR NONLINEAR COINTEGRATION

We use unit root test analysis to examine the potential cointegration relationship between energy use (kilogramme of oil equivalent per capita) and GDP per capita of EU-15 countries from 1960 to 2009. The data are from the World Development Indicators (WDI, 2004). However, the country sample depends not only on the availability of data. We should also take into account the environmental performance of the countries, their idiosyncratic characteristics, economic structures, the quality of their institutions as well as their participation in economic blocks with common environmental policies, which can all be very relevant in such a study.

The series were transformed into logarithms.

$$y_{ti} = \alpha - \log(EU_{pci}) - \beta \log(GDP_{pci}) + u_t \tag{21}$$

where EU_{pci} and GDP_{pci} stand for energy use per capita and gross domestic product of country i respectively. Our actual interest focuses on the long-term equilibrium relationship linking both series, in other words: Do GDP_{pci} and EU_{pci} share a common stochastic and deterministic trend?

In order to do so and using the concept of cointegration as a basis, we analyze whether permanent movements in one series are associated to permanent movements in the other. In equation (1) this involves testing whether u_t is a stationary process, which implies that EU_{pc} and GDP_{pc} must be cointegrated. Instead of imposing a [1, -1] cointegrating vector, we relax the assumption of perfect cointegration to allow for alternative stationarity relationships other than strict proportionality. In particular β will take up to 15 different values[1].

Ogaki and Park (1997) proposed distinguishing between stochastic and deterministic cointegration. While *stochastic cointegration* only requires the stochastic trend components of the series to be cointegrated, *deterministic cointegration* requires the cointegrating vector to remove both the stochastic and the deterministic trends from the data. This restriction, according to Park (1992), yields important efficiency gains when estimating the cointegrating vector.

1 We set the variable $y_{ti} = EU_{pci} - (\mathrm{H}/10) \times GDP_{pci}$ where H takes the following values: 1 2 4 6 8 12 14 16 18 20 22 24 26 28 30

Although the Kapetanios et al. (2003) nonlinear unit root test allows us to detect nonlinear stationarity in the series, as it does not include a deterministic trend, it cannot distinguish between the two different concepts of cointegration. The Chong et al. (2008) test avoids this problem by modifying the Smooth Transition Autoregressive (STAR)-type statistic model proposed by Kapetianos. More specifically, Chong estimates the following model:

$$\triangle y_{it} = \mu + \sum_{j=1}^{p} \rho_j \triangle y_{it-j} + \delta y_{it-1}^3 + \varphi G(T) + \varepsilon_{it} \tag{22}$$

where G(T) is a trend component of a specific functional form (either a linear trend or the square of a linear trend). From Equation (2), the absence of a nonlinear unit root $(\delta < 0)$ implies either nonlinear *stochastic cointegration*, given the presence of a deterministic trend $(\varphi \neq 0)$, or nonlinear *stochastic cointegration* if a deterministic trend is absent $(\varphi \neq 0)$. However, if $(\delta = 0)$, the path between EU_{pc} and GDP_{pc} is said to diverge over time.

4.3 RESULTS AND CONCLUSIONS

For the sake of comparison we avoid the a priori exclusion of linear models by applying both linear and non-linear tests. Thus, we first test for the existence of an EU_{pc}-GDP_{pc} cointegration relationship using the MZ_{α}^{GLS} standard linear test proposed by Ng and Perron (2001). The results are presented in Table 1, where there is strong evidence of no long-run equilibrium between energy use and GDP, as we cannot reject the null hypothesis of no cointegration for any of the countries except Italy.

Based on these results, we could conclude that the EUpc and GDPpc series are not in long-run equilibrium, however, this may result from failing to account for the possibility of a structural break. It is well known that if a structural change in the deterministic structure exists, the unit root test has low power. We therefore apply the LM test proposed by Lee and Strazicich (2003), which allows for up to two breaks in the level, or for simultaneous changes in the level and slope in a linear setting.

The last columns in Table 1 report the evidence obtained using the different structural break models considered in the Lee and Strazicich (2003) test. L and S stand for breaks in the level and slope respectively, whereas the number of changes is in brackets. The evidence from considering potential structural change is not very different to that derived from the Ng and Perron test, as there is only slightly more evidence of cointegration or long-run equilibrium between $EU_{pc}$and GDP_{pc}.

Notwithstanding, the strong evidence rejecting cointegration in the EU_{pc}-GDP_{pc} relationship may be caused by the functional form specified when it is analyzed. Indeed, if either EU_{pc} or GDP_{pc} behave globally as stationary, but the adjustment towards equilibrium is nonlinear, linear tests may spuriously detect a unit root in the residuals of the EUpc-GDPpc relationship.

More specifically, the results of the nonlinear Chong test in Table 2 show that there is evidence of cointegration for countries that are actually struggling to comply with Kyoto commitments. The European Environment Agency (EEA) has published a report presenting an overview of the progress achieved so far by the EU countries in regard to their respective targets under the Kyoto Protocol. On page

Table 23: Results of Linear Test

Countries	MZ_{α}^{GLS}	Lag	L(1)	L(1)S(1)	L(2)	L(2)S(2)
Austria	-1.518	5	**-3.5793****	**-4.8586****	**-4.7773*****	**-5.8475****
Belgium	-2.297	1	-2.5708	-3.0953	-3.4388	-4.5105
Denmark	-1.797	4	-1.7377	**-4.3433***	-1.9239	-5.0288
Finland	-1.624	1	-2.3959	-3.2388	-3.1838	-4.7714
France	-1.301	5	**-3.2842***	-3.7001	**-3.7548***	-4.1344
Germany	-1.466	4	-1.946	-3.279	-2.4547	-4.0845
Greece	-0.432	2	-0.994	-2.0331	-1.3003	-3.4362
Ireland	-0.648	1	-1.4404	-2.2875	-1.3211	-4.0383
Italy	**-3.137***	2	-0.9066	-1.916	-1.5017	-3.28
Luxembourg	-1.872	1	-1.3177	-2.6561	-1.8864	-4.1691
Netherlands	-1.072	1	-1.1411	**-4.2822***	-1.3628	-4.6549
Portugal	-1.267	2	-2.2941	-3.8235	-2.3313	**-6.383*****
Spain	-0.399	8	-1.2027	-2.4143	-1.959	-2.7342
Sweden	-0.369	1	-1.6106	-3.1403	-2.0808	-4.7744
United Kingdom	-1.262	1	-1.9884	-2.6428	-2.4818	-4.1796

Notes: The lag order selected is based on the MAIC, as proposed by Ng and Perron (2001).
*,**,*** The null hypothesis is rejected at the 1%, 5% or 10% level.

Table 24: Results of Non Linear Test

Linear trend			**Squared trend**		
Country	*t-statistic*	*Trend*	*Country*	*t-statistic*	*Trend*
Austria	-3.69154**	-3.97451***	Austria	-3.28357*	-3.40397**
Italy	-4.76583***	1.99738	Denmark	-3.11939*	-3.76109**
Portugal	-3.86993**	4.09202***	Italy	-5.97119***	2.25509
Spain	-4.44014***	-3.72603**	Netherlands	-4.08733***	-4.30301***
			Portugal	-4.06953**	4.05394***
			Spain	-6.05651***	-5.34262***

Notes: ***,** and * denote significance at 1%, 5% and 10% respectively. BIC criterion is used to select the appropriate order of lag.

8 a figure displays the gap between emissions in 2008 and Kyoto targets. Spain, Italy, Austria, Denmark, Ireland, Luxembourg, Portugal and the Netherlands have performed the worst, as they display the widest gaps.

When a non-linear trend is specified, our empirical results show a very similar pattern to that outlined by the EEA. Out of the 8 countries with the largest gap, five are identified by means of the non-linear methodology, as they display a proportional long-term relationship between GDP and energy use. These countries will face higher costs to achieve their objectives.

From a policy-oriented point of view, the main conclusion is that the countries that should be asked to make further efforts to achieve Kyoto targets. To achieve as global a ratification as possible of the new environmental agreement that replaces the current Kyoto Protocol, the compliance of EU-15 countries is a critical issue. Otherwise, evidence of proportional growth between energy consumption and GD worsens negotiation and discourages emerging countries from adopting environmental measures, as rich countries can more easily afford cleaner technologies, the use of renewable energies or any other mitigating factor. As a result, their higher level of output should not be accompanied by a proportional increase in emissions.

APPENDIX: IS THERE ECONOMIC GROWTH DEPENDENCE ON FOSSIL-FUEL CONSUMPTION?: NONLINEAR DETERMINISTIC CONVERGENCE ANALYSIS.

INTRODUCTION

Fossil fuels are currently the main energy source. Their combustion produces the damaging greenhouse gases, which are responsible for the troubling global warming effect. Unfortunately there are several gases associated with the green house effect. Although CO_2 is not the gas with the strongest radioactive effect, this paper focus on it, as it is the gas with the longest life cycle, persisting around a hundred years and trapping two thirds of the total radioactivity in the atmosphere IPCC (2001).

Since the vast majority of the economic activities require energy, emissions and gross domestic product (GDP) are closely related. Therefore it seems likely that an econometric relationship between both variables exists.

At this point the following crucial question is formulated: Do countries' growth depend on fossil-fuel consumption? A positive answer to this question is controversial, in that, if fossil-fuel consumption results in higher levels of GDP, instituting policies and protocols to reduce the current CO_2 emissions levels will have effect on economic growth.

These negative effects will be even worse in developing countries as they are in a preindustrial stage, which, in fact, usually specialize in energy intensive sectors.

Therefore environmental policies have become a topic of concern not only to scientists but also to economists, since the efforts to prevent climate change may also reduce economic activity. Thus, it is crucial to empirically determine whether policy makers face a trade-off between the restriction of CO2 emissions and economic growth.

Due to the importance of the impact of CO2 emissions reduction on the countries' development, recently their causal relationship has been widely studied. However, as it can be seen in the complete surveys of Chontanawat et al. (2006), Huang et al. (2008), Ozturk (2010)and Payne (2010b)the empirical results have been mixed.

Although the former authors point to reasons such as different econometric methodologies and countries' characteristic as a source of the ambiguous evidence in this paper we focus on the functional form as the more important reasons of the mixed finding. Camarero et al., (2011, Section 2) provide several arguments supporting that CO2-GDP relationship could be nonlinear. Specially, they point up to forth potential sources of nonlinearity: energy prices driving different levels of GDP and consequently in CO2 emissions; changes in specialization sector from manufacturing to service sector; changes in the perception of environmental as a normal to a luxury good produce different levels of CO2 emissions; finally if the Pollution Haven Hypothesis (PHH) and the Porter Hypothesis are verified both will produce shift on CO2 levels.

Standard unit root tests assume that deviations from the long-run equilibrium are symmetric, constant and occur every period. These assumptions would imply that economic agents react simultaneously to a given economic shock, however there are some economic reasons that do not hold them. For instance, progressive investment in cleaner technology to fulfil their commitments under environmental regulations implies a deviation from the long-term equilibrium that series only revert when some periods elapse. Moreover asymmetry can be expected due to countries' fossil-fuel dependence. Therefore based on these characteristic of the CO2-GDP ratio, assess this relationship by linear methodology could bias the tests to the non stationary hypothesis which means that the no long run equilibrium hypothesis cannot be rejected.

Nevertheless, the linear methodology is commonly used in the empirical literature to analyze CO2-GDP relationship. In order to circumvent this bias could be used a model whose deterministic structure takes into account a gradual rather than an instantaneous adjustment. To capture this type of variables, the regime-switching models that allow continuous changes between regimes are the more suitable ones, so this is the reason why we apply smooth transition autoregressive (STAR) models in this paper.

Therefore we investigate if there is long-term equilibrium in the relationship between GDP and CO2 emissions using non-linear methodology rather than the linear one commonly used in the empirical literature. Specially, we assess if a shock in either CO2 or GDP produces only a transitory deviation from the long run equilibrium which implies that both variables are cointegrated. For that purpose we use the test proposed by Kapetanios et al. (2003) with the novelty introduced by Chong et al. (2008) which allow us not only the assessment of long-run co-movements between both variables caused by stochastic elements, meaning stochastic convergence, but also deterministic convergence by analyzing the deterministic trend. This long-term information is of undeniable importance to policy makers as evidence in favour of convergence reveals that any stabilizing energy policy will have long-lasting effects on countries' economic growth.

2. METHODOLOGY AND DATA TESTING FOR NONLINEAR CONVERGENCE

Using unit root test analysis we examine the potential convergence relationship between annual metric tons of CO2 emissions and the GDP of 59 countries from 1950 to 2007. Both GDP and CO2 emissions variables are measured on a per capita basis (GDP pc and CO2pc hereafter). The series were transformed into logarithms.

$$Z_{ti} = \alpha - \log\left(CO_{2pci}\right) - \beta \log\left(GDP_{pci}\right) + u_t \tag{23}$$

Our actual interest is focused on the long-term equilibrium relationship linking both series, in other words: Are GDP_{pc} and CO_{pc} sharing a common stochastic trend?

Convergence has been traditionally defined and tested in the context of cross-section data in the economic growth literature, as in Barro and Sala-i Martin (1992). The time series approach by Bernard and Durlauf (1995) asks whether permanent movements in one series are associated with permanent movements in another series, that is, it examines, whether common stochastic elements matter, and how persistent the differences among both series are.

Therefore the time series framework is based in the convergence concept and involves tests for stationarity of differentials between the two series. This means assessing if the deviation u_t in equation 1 is a stationary process which implies that CO2 and GDP series must be cointegrated.

However, Oxley and Greasley (1995) and Bernard and Durlauf (1996) stated that non unit root in the differences between series should not be necessarily taken as evidence of divergence. These authors have proposed the distinction between two degrees of convergence: long-run convergence and catching-up, yielding to an appropriate test framework based on convergence techniques. The latest concept is the suitable for the sample we are analyzing as at least for the emerging countries, a long rung equilibrium between CO2 and GDP series might be an on-going process due to their lower industrialized state.

Furthermore as noted by Kapetanios et al. (2003) linear unit root tests might suffer from lack of power in the presence of nonlinearities in the dynamics of the variables and, hence, they might be not able to distinguish between unit root and nonlinear stationary process so they are bias to the non convergence hypothesis.

Accordingly this paper takes into account these two potential sources of ambiguity in the previous studies allowing for: first a clear differentiation between the concept of catching-up (a transition process) and long-run equilibrium (a completed process) and additionally the presence of non-linearities in the CO2-GDP relationship.

Non Linear Unit Root: KSS Test

The following autoregressive specification could be the model of any standard unit root test:

$$\triangle Z_t = \mu + \rho Z_{t-1} + \alpha t + \sum_{k=1}^{n} \triangle Z_{t-k} + \varepsilon_t \tag{24}$$

where μ is the mean of the variable Z_t and ε_t represents the error term.

$$Z_t = \log CO_{2pc} - \log GDP_{pc} \tag{25}$$

However, as Kapetanios et al. (2003) notes, if the variable Z_t in equation (3) exhibits nonlinearities, the standard tests tend to have low power. They propose a test (KSS, hereafter) where the null hypothesis is a unit root against a globally stationary ESTAR process. They consider the following data generating process:

$$Z_t = \beta Z_{t-1} + \gamma Z_{t-1} \Theta \left(\theta; Z_{t-d}\right) + \varepsilon_t \qquad t = 1, ..., T \tag{26}$$

This is a STAR (1) model with unknown parameters. Kapetanios et al. (2003) assume that the transition function adopts an exponential form,

$$\Theta \left(\vartheta; Z_{t-d}\right) = 1 - e^{\left(-\vartheta z_{t-d}^2\right)}$$

where $\theta \geq 0$ and $d \geq 1$ is the delay parameter. The transition function is bounded between 0 and 1, and it is symmetrically U-shaped around zero:

$$\Theta : R \rightarrow [0, 1]; \qquad \Theta(0) = 0 \qquad \lim_{x \to \infty} \Theta\left(x\right) = 1$$

Thus the model obtained is an exponential STAR (ESTAR):

$$Z_t = \beta Z_{t-1} + \gamma Z_{t-1} \left[1 - e^{\left(-\vartheta z_{t-d}^2\right)}\right] + \varepsilon_t \qquad t = 1, ..., T \tag{27}$$

This can be reparameterised as:

$$\triangle Z_t = \phi Z_{t-1} + \gamma Z_{t-1} \left[1 - e^{\left(-\vartheta z_{t-d}^2\right)}\right] + \varepsilon_t \tag{28}$$

with $\phi = \beta - 1$

It is assumed that $\phi = 0$ implying that Z_t follows a unit root process in the middle regime. Additionally for $d = 1$,

$$\triangle Z_t = \gamma Z_{t-1}\left[1 - e^{\left(-\vartheta z_{t-d}^2\right)}\right] + \varepsilon_t$$

The null hypothesis is a linear unit root:

$$H_0 : \phi = 0$$

But the test focuses on parameter θ, which is $\theta = 0$ under the null hypothesis and positive under the alternative. Thus, if $H_0 : \phi = 0$ and $\theta > 0$ then Z_t follows a nonlinear but globally stationary process.

Testing the null directly is not feasible since γ is not identified under the null. Kapetanios et al. (2003) following Luukkonen et al. (1988), overcomes the problem using a t-type test statistic. Computing a first-order Taylor series approximation to the ESTAR model under the null hypothesis, the following auxiliary regression is obtained:

$$\Delta Z_t = \delta Z_{t-1}^3 + error \tag{29}$$

From this regression a t-statistic can be obtained to test for the null hypothesis $\delta = 0$ against the alternative of δ<0 as:

$$t_{NL} = \frac{\hat{\delta}}{s.e.\left(\hat{\delta}\right)}$$

where $\hat{\delta}$ denotes the OLS estimated parameter of δ and s.e. stands for the standard error of $\hat{\delta}$.

Test Allowing for Catching-up (Deterministic Convergence)

While stochastic convergence examines only the cancellation of the stochastic trend between $CO_{2pc} - GDP_{pc}$, deterministic convergence is a stricter notion of convergence since it means that both variables share the two types of trends: the stochastic and the deterministic trend.

The assessment of the deterministic trend allows us to analyze the different concept of long-run equilibrium and catching up which is crucial in the CO2-GDP relationship due to several countries might be no wholly industrialized. Additionally a significant deterministic trend suggests several implications for policy makers about important issues such as energy efficiency. For instance, it could mean that GDP grows relatively faster than CO2 emissions. Accordingly, countries growth does not involve necessarily a proportionally CO2 emissions increase, as they achieve energy efficiency. An additional reason why it is worthy studying the deterministic trend is that a significant deterministic may suggest changes in structural behaviour of the GDP-CO2 relationship due to the fact that manufacturing is losing a share of GDP.

Let us assume that GDP and the CO2 emissions are difference stationary processes with drift:

$$GDP_t - GDP_{t-1} = \mu_{GDP} + u_t \tag{30}$$

$$CO_{2t} - CO_{2t-1} = \mu_{CO_2} + v_t \tag{31}$$

where $u_t$and $v_t$are stationary with mean zero. Recursive substitution in (9) and (10) yields:

$$GDP_t = \mu_{GDP} t + GDP_t^0 \tag{32}$$

$$CO_{2t} = \mu_{co_2} t + CO_{2t}^0 \tag{33}$$

where GDP_t^0 and CO_{2t}^0 are difference stationary processes without drift. t is the deterministic trend that can be either linear or nonlinear t^2.

If there is a β such that:

$$GDP_t = \theta_\beta + m_\beta t + \beta CO_{2t} + \epsilon_t \tag{34}$$

is trend stationary, GDP and CO2 are converging stochastically. Therefore, this convergence concept only requires that the stochastic trends of the two variables are cancelled. However, there is deterministic convergence if in (13), $m_\beta = \mu_{GDP} - \beta\mu_{CO_2}$ satisfies the following restriction:

$$\mu_{GDP} = \beta\mu_{CO_2} \tag{35}$$

This means that the cointegrating vector that removes the stochastic trends also eliminates the deterministic trends. Thus, if the restriction is satisfied, then

$$GDP_t = \theta + \beta CO_{2t} + \epsilon_t \tag{36}$$

and GDP and CO2 are converging.

The KSS statistic shown in equation (7) enables us to test for nonlinear stochastic convergence. In addition, we can test for deterministic convergence, that not only implies that the variable Z_t must be I(0) but also that the deterministic trend is significant. Nevertheless, according to Chong et al. (2008) the KSS test does not allow for this specification concerning the trend component.

In order to overcome this problem they add both an intercept (μ) and a trend G(trend) into the specification in equation (7):

$$\triangle Z_t = \mu + \delta Z_{t-1}^3 + \phi \left[G \left(trend \right) \right] + error \tag{37}$$

As in Chong et al. (2008) we specified for G(trend) a quadratic functional form.

Therefore, now we can test for deterministic convergence, that is, whether the relationship $Z_t = \log CO_{2pc} - \log GDP_{pc}$ including a deterministic trend is either stationary or trend stationary.

DATA AND EMPIRICAL RESULTS

Data on annual CO2 emissions in metric tons have been provided by the Carbon Dioxide Information Analysis Center (CDIAC) whereas data on GDP have been obtained from the World Development Indicators (WDI) database. Our sample consists of 59 countries covering the period from 1950 to 2007. Both variables are measured in per capita terms using population data provided by Maddison (2007).

For the sake of comparison we avoid the a priori exclusion of linear models by applying both linear and non-linear tests. Thus we first test for the existence of a CO2pc -GDPpc convergence relationship using a standard linear test. The results are presented in Table 1. The ratio fractional number entries indicate the number of countries that the CO2pc -GDPpc relationship have been found to be stationary . Applying the MZ_{α}^{GLS} proposed by Ng and Perron (2001) there is clear evidence that for many countries the null hypothesis of non stochastic convergence between CO2pc and GDPpc cannot be rejected.

Based on these results we could conclude that CO2pc and GDPpc series are not in long-run equilibrium, thus any environmental policies instituted to reduce fossil fuel dependency would have any effects on economic growth. However, this may result from the failure to ignore the possibility of a structural break, as it is well known that if a structural change in the deterministic structure exists the unit root test have low power.

Table 25: Linear test Fossil Fuel Dependence

CO_{2pc}-GDP_{pc}	
TEST	**Number of I(0) variables**
MZ_{α}^{GLS}	0/59
L(1)	10/59
L(1)S(1)	16/59
L(2)	12/59
L(2)S(2)	17/59

To take into account the potential structural breaks that may exist in the CO2pc -GDPpc relationship, we apply the LM test proposed by Lee and Strazicich (2003) that allows for up to two breaks in the level, or for simultaneous changes in the level and slope in a linear setting. The last rows of Table 1 reports the evidence obtained using the different structural break models considered in the Lee and Strazicich test. "L" and "S" stand for that the break occurring in the level and in the slope respectively, whereas the number of changes is in parentheses. In comparison with the Ng and Perron test, there is a slight larger evidence of convergence or long-run equilibrium between CO2pc and GDPpc, especially when the model is specified with a shift in both the level and the trend. We obtain the strongest evidence in favour of stationary in a model specified with one and two changes in the slope and in the level. However this evidence is not large enough to conclude that fossil-fuel consumption is not a limiting factor to economic growth and, hence, shocks to fossil-fuel use will have not any negative impact on economic growth.

The reason for the non-rejection of the unit root hypothesis may be indeed the absence of stochastic convergence between CO2pc and GDPpc. Notwithstanding the strong evidence of non stationarity, the rejection of convergence in the CO2pc -GDPpc relationship, may be caused by the functional form specified when it is analyzed. Neither the Ng-Perron test, nor the Lee-Strazicich tests with a linear trend would be able to detect stochastic convergence if either CO2pc or GDPpc are non linear. Indeed, if the variables behave globally as stationary but the adjustment towards equilibrium is nonlinear, linear tests may spuriously detect a unit root in the residuals of the CO2pc -GDPpc relationship.

Accordingly we assess whether the use of a non-linear approach may reverse the conclusions reached using linear approaches.

Within the STAR methodology the KSS test enables us to analyze whether CO2pc and GDPpc contain the same stochastic trend so that Z_{ti} in (1) is stationary. This implies that there is stochastic convergence, so that CO2 emissions and GDP have a long-run equilibrium relationship. In addition, the Chong et al. (2008) tests allow us to gain valuable information about the behaviour of the deterministic components of both variables. Chong et al. (2008) consider the two cases commonly used, a deterministic linear trend and a quadratic trend.

Additionally, instead of imposing that if there is a cointegrating vector [1, -1] we relax the assumption of perfect convergence allowing for alternative stationarity relationships other than the strict proportionality. Thus, we test for the following convergence vector:

$$Z_{ti} = GDP_{pc} - \beta CO_{2pc} \tag{38}$$

where β will take up to 15 different values .

Table 2 shows the results of the KSS test with a non-linear trend. The rejection of the null hypothesis is quite robust to the criterion chosen. Up to 44 out of the 59 countries the unit root hypothesis is rejected following AIC and HQ criteria. Using the MAIC criterion of Ng and Perron (2001) to select the lag length, there are even less unit root rejections, taking into account that this criterion yield huge test' size improvements. The CO2pc-GDPpc long-term equilibrium is found for Bulgaria, China, Congo, Dominican, Finland, Grenada, Guyana, Hong Kong, Hungary, Norway, Taiwan and UK. Thus, there is mixed evidence between developed and developing countries. Going into details the evidence of convergence is higher for emerging countries than for industrialized ones.

Table 26: KSS Test -Non Linear Trend Fossil Fuel Dependence

TEST/CRITERION	AIC	BIC	HQ	MAIC
KSS	44/59	43/59	44/59	43/59
OECD countries (KSS)	17/44	17/43	17/44	17/43
Catching-up $(\phi^2 \neq 0)$	23/44	22/43	22/44	23/43
OECD countries $(\phi^2 \neq 0)$	10/23	9/22	9/22	10/23

For those cases in which we reject the unit root hypothesis, we can further assess whether the trend is significant allowing distinction between long-run convergence and convergence as catching-up. The third row of Table 2 shows that about half of countries are converging as catching-up rather than in long-term way. As we can expected the catching-up process is mostly find in OCDE countries in are lower as can be seen in the last row of Table 2.

CONCLUSIONS

In this paper we check whether the empirical evidence regarding CO2pc-GDPpc relationship is still controversial due to the methodology employed. Unlike many previous works a nonlinear methodology is applied. From the results obtained two issues become evident: First, the adequacy of using nonlinear methods, as they do not confuse the non linearity or a gradual response to a shock with the presence of a unit root. Second, the evidence of long-run equilibrium between CO2 and GDP is quite robust to the lag specified, even based on the stringent criterion MAIC, the hypothesis of convergence could be rejected for most of the countries.

We consider that these results have several important policy implications. The strong evidence of a relationship linking CO2 emissions and GDP indicates that fossil-fuel consumption abatement will have negative effects on economic growth.

Furthermore the findings achieved show a different pattern among countries that can be based on the degree of development. The fact that the long-run equilibrium is less evident in industrialized countries may be due reasons as can afford cleaner technologies, thus a higher output level is not follows by a proportional increased emissions. The same occurs with the use of renewable, or any other dampening factor.

However our sample includes countries that have not yet begun their economic development, thus their industrialized degree is lower. But the idiosyncratic characteristic of their own economic structure is not the only source of differences: the quality of their institutions as well as their participation on economic blocks with a common design of their environmental policies can be also relevant. Thus, to take into account these heterogeneous distinctions is important to test statistically for long-run convergence and catching-up.

The empirical results regarding catching-up indicate that countries for which the historical relationship between GDP and CO_2 emissions still cannot reveal the long-run equilibrium but a transition process are mostly emerging ones.

Therefore the empirical results we have obtained should not lead the politicians to impose emission reductions regardless of whether the country is a developed one or those remaining in a pre-industrial state. Moreover, the results call for further analysis to understand whether the reasons behind of less evidence of long-run equilibrium between GDP and CO_2 in industrialized countries could be technological development resulting in energy efficiency, environmental regulations or perhaps we should think about the pollution haven hypothesis postulates: Have industries been migrating from developed economies to the developing countries looking for weaker environmental standards? Are international trade flows switching due to difference in environmental stringent?.

5

VARIABLE SELECTION IN THE ANALYSIS OF ENERGY CONSUMPTION-GDP NEXUS

5.1 INTRODUCTION AND MOTIVATION

There are several economic theories that have traditionally been applied to the relationship between energy consumption and growth. A specific debate spans two economic theories; ecological economic theory and neoclassical growth theory. Ecological economic theory considers the scarcity of energy resources as a limitation to growth. In contrast, neoclassical growth theory (such as Solow's 1956 model) states that energy resources are not essential inputs for growth. Ecological economic theory argues that scarcity problems may be circumvented thanks to technological progress and substitution possibilities.

Which hypothesis prevails has direct policy implications? If energy is a neutral input for growth, policymakers could simultaneously design environmental conservation policies and economic growth strategies. Conversely, ecological economists argue that a sustainable growth path would be hard to achieve if energy sources are a critical input.

An abundance of empirical literature has attempted to address this issue over the last 30 years, beginning with the seminal paper byKraft and Kraft (1978). To classify the evidence produced since this paper, four generations of studies are mentioned in the literature.[1]

1 See for example Belke et al. (2011)

The first generation of studies applies Sims (1972) VAR methods to analyse causality between energy consumption (EC) and GDP. GDP is used as a proxy for economic growth. However, these studies do not account for the time series properties of the variables, i.e., their order of integration. The second generation of studies attempts to overcome this limitation by using the Engel and Granger cointegration approach that allows for non-stationary variables.

The main drawback of this technique is a limited analysis of a bivariate setting and, therefore, a third generation of studies extends the framework to a multivariate perspective as in Johansen (1991). A fourth, more recent generation of studies has attempted to avoid the problems of a short data span that complicates the application of multivariate methods for many countries. Panel estimation techniques provide consistent estimates of the long-term relationships and, at the same time, account for cross-sectional information and compensate for the scarcity of time series data for some variables. However, the results for the nexus EC-GDP are inconclusive and are demonstrated by the surveys of Ozturk (2010), Payne (2010a) and Coers and Sanders (2013). The main reasons given in the literature for these discrepancies are the application of a variety of econometric approaches, the heterogeneity of the countries analysed and the differences in the time span of the samples. Additionally, certain authors argue that the main factors that explain the mixed evidence are the limitations of the bivariate approach and the associated problem of omitted variables There are multiple potential channels that can influence such a complex relationship, and the bivariate approach may be concealing the majority of these channels. This omitted variable bias has been addressed by the introduction of several control variables. Table 1 presents several of the most widely used variables in the literature that we added to our study database[2].

2 For more detail see Appendix.

Table 27: Control Variables used in the literature GDP-EC nexus

VARIABLES	REASONS	AUTHORS
Employment (EMP)	Economic growth depends on other variables such as technology, energy and employment.	Yu and Hwang (1984); Stern (1993); Cheng (1998); Ghali and El-Sakka (2004); Soytas and Sari (2006); Climent and Pardo (2007); Bowden and Payne (2010); Lee and Chang (2008); Lee et al. (2008c); Sari et al. (2008); Bartleet and Gounder (2010); Menyah and Wolde-Rufael (2010); Shahbaz et al. (2011); Eggoh et al. (2011); Menegaki (2011); Yildirim et al. (2012); Soytas and Sari (2007); Payne and Taylor (2010)
Energy Prices: Natural Gas Price (NG_P), Coal Price (C_P), Oil Price (O_P), Energy Price Index.	Crucial role of energy costs in the production function.	Glasure and Lee (1995, 1996); Glasure (2002); Lee and Lee (2010); Costantini and Martini (2010); Belke et al. (2011)
Government Spending (SPE)	Governments may use active monetary and fiscal policies to compensate for the negative effects of energy shocks (i.e., oil shocks).	Glasure and Lee (1996); Glasure (2002); Akinlo (2008)

Gross Fixed Capital Formation: Private Investment (PI), Fixed Investment (FI), No Residential Investment (NR), Structural Investment (SI), Equipment and Software Investment (ESI), Residential (R), Public Investment (IPU).	Employment and capital are arguments in any aggregate production function. Also used in neoclassical literature to capture energy substitution effects.	Stern (1993, 2000); Cheng (1996); Cheng and Lai (1997); Cheng (1998, 1999); Ghali and El-Sakka (2004); Oh and Lee (2004b,a); Lee (2005); Soytas and Sari (2006); **?**); Soytas et al. (2007); Bowden and Payne (2010); Lee and Chang (2008); Lee et al. (2008c); Payne and Taylor (2010); Yuan et al. (2008); Bartleet and Gounder (2010); Menyah and Wolde-Rufael (2010); Eggoh et al. (2011); Yildirim et al. (2012); Coers and Sanders (2013); Apergis and Payne (2009); Payne (2009)
Money Supply (RMO)	According to Glasure and Lee (1996) “the combined effects of money and government expenditure in the relationships between US energy consumption and employment components account for more than 35% of the variance in energy consumption”.	Glasure and Lee (1996); Glasure (2002)
Energy Intensity (EIN)	Employed to represent increases in efficient energy use, as well as to capture structural changes in the economy.	To the best of our knowledge in the context of this literature, this variable was not included explicitly in the studies.
Energy Efficiency (EEF)	Efficiency changes may be a suitable variable to explain the dynamics of the relationship EC-GDP.	The same as EIN.

Source of energy production: Coal (COAL), Natural Gas (GAS), Crude Oil (OIL), Natural Gas Plant Liquids (NGPL), Nuclear (NUC).	The disaggregation of different energy sources allows a better understanding of the EC-GDP ratio	Yu and Choi (1985); Fatai et al. (2004); Wolde-Rufael (2004); Lee and Chang (2005); Zamani (2007); Yuan et al. (2008); Sari et al. (2008); Yang (2000)
Consumer Price Index (CPI)	Sometimes used as a proxy for energy prices.	Bartleet and Gounder (2010); Eggoh et al. (2011); Kahsai et al. (2012)
Business sector Productivity (B_P), No farm business sector Productivity (NF_P), No financial corporate sector Productivity (NFI_P)	Labour productivity can be decomposed into: energy productivity (GDP per energy unit) and energy intensity (energy per labour unit). Sustainable growth not only implies an increase in energy efficiency but also of other inputs productivity, such as labour and capital.	Taylor (2008)
Exports: Goods Exports (X_G), Services Export (X_S) Imports: Goods Imports (M_G), Services Imports (M_S)	Both exports and imports are major variables to a first approximation to the Pollution Haven Hypothesis[3].	Narayan and Smyth (2009); Lean and Smyth (2010a,b); Sadorsky (2011, 2012)

3 The Pollution Haven Hypothesis (PHH) states that trade and capital liberalisation may shift pollution-intensive activities from countries with stringent environmental regulation to the countries with lax regulations. To test for the PHH it would be necessary to conduct a more detailed disaggregation of the trade data into clean and "dirty" imports and exports and the bilateral flows among the classified countries, taking into account their levels of environmental regulation stringency.

However, to the best of our knowledge, the control-variables have frequently been chosen "ad hoc", with the result that the studies in most cases lack statistical motivation. Due to the complexity of this relationship, and the multiple causality channels that can affect it, this is a crucial issue that deserves consideration. From an application perspective, the task of selecting the control variables is complicated because it generates multiple combinations between the main relationship and all of the potential control variables. The main contribution of this study therefore consists of the application of a Bayesian variable selection procedure that, by considering economic growth as exogenous, allows for an a priori evaluation of the probability of including a variable in the model selected from a large group of possible candidates. We apply this methodology to US data for the aggregate variables and for the sector breakdown of GDP and the sources of energy consumption. The United States was chosen for two reasons: first, the availability of data for both the longer time span and for a significant set of related variables and sector disaggregation; second, the United States is responsible for one of the largest world shares of pollutants emissions.

In the following section, we present a brief summary of our methodological approach. The third section describes the data and includes a discussion of the results. Finally, section four presents the conclusions of the study.

5.2 ECONOMETRIC METHODOLOGY

5.2.1 *Bayesian methods for model selection*

We have argued that an important aspect in the analysis of the relation between GDP and EC is the incertitude regarding the role of certain variables as control variables. The potential impact of these variables on GDP is endorsed by the specialised literature (see **??**) but their ultimate presence in the model response is unknown. A central motivation in this paper is that this major source of variability should not be obviated and that we formally consider it through the Bayesian paradigm. This type of situation defines a particular model selection problem known as variable selection, formally introduced in the next section.

The uncertainty that occurs as a result of the ignorance on which the statistical representation that most adequately explains a response variable is based, is explicitly considered in *model selection* problems. These problems contrast with *estimation* problems where the underlying statistical model is assumed to be known. *Model selection* is an intricate discipline of statistics that has theoretical roots in hypothesis testing and decision theory and that has been especially active in recent years.

The Bayesian approach to model selection has a number of properties that are described in detail in Berger and Pericchi (2001) and that cause it to be an appealing and solid methodology. However, this paper takes advantage of a lesser known and barely exploited characteristic of this methodology, which relates to the richness and interpretability of results. The end product of the Bayesian approach is the so-called posterior distribution over the model space; a probability mass function that assigns to each entertained model its probability conditional on the data observed. What makes this function so rich and useful is that it permits the evaluation of any relevant question to the analyst in probabilistic terms, which may be argued to be the natural way to report evidence. The probability that EC influences GDP once all control variables are considered can be assessed in the light of the data observed. This type of summary that we introduce in 5.2.2 is called an *inclusion probability*.

5.2.2 *The Variable Selection problem*

With respect to variable selection, each entertained model corresponds to a specific subset of a group of (e.g., p) of initially considered potential explanatory covariates. Therefore, the model space has 2^p models. In this paper, we consider variable selection in a linear context and in particular, each model M_i for $i = 0, \dots, 2^p - 1$ relates the response variable to a subset of k_i covariates, such as:

$$\boldsymbol{y} = \beta_0 \mathbf{1}_n + \boldsymbol{X}_i \boldsymbol{\beta}_i + \boldsymbol{\varepsilon} \quad \boldsymbol{\varepsilon} \sim \mathcal{N}_n(\mathbf{0}, \sigma^2 \boldsymbol{I}) \tag{39}$$

where $\boldsymbol{y}$ is the $n \times 1$ vector of observations for the response variable: $\boldsymbol{X}_i$ is the $n \times k_i$ design matrix; $\boldsymbol{\beta}_i$ is the $k_i \times 1$ vector of linear regressors and β_0 denotes the intercept (contained in all models). Following this notation, M_0 is the model just containing the intercept only. Finally, $\boldsymbol{\varepsilon}$ is a white noise error. We denote $M_i(\boldsymbol{y} \mid \boldsymbol{\beta}_i, \boldsymbol{\beta}_0, \sigma)$ to be the corresponding joint density of the random vector $\boldsymbol{y}$ under M_i. The posterior distribution assigns its conditional posterior probability to each model given the data and is formally defined by the Bayes theorem:

$$P(M_i \mid \text{data}) = m_i(\boldsymbol{y})\, P(M_i)/C.$$

Above, $P(M_i)$ is the prior probability, C is the normalising constant and $m_i(\boldsymbol{y})$ is the marginal density for $\boldsymbol{y}$ under model M_i:

$$m_i(\boldsymbol{y}) = \int M_i(\boldsymbol{y} \mid \boldsymbol{\beta}_i, \boldsymbol{\beta}_0, \sigma)\, \pi_i(\beta_0, \boldsymbol{\beta}_i, \sigma)\, d\beta_0\, d\boldsymbol{\beta}_i\, d\sigma, \tag{40}$$

where π_i is the prior distribution for the model-specific parameters of M_i and the most problematic ingredient in the whole setting. The prior that we used, and the motivation for its use, has several technicalities that are described in the following section to improve the readability of the study. An important practical aspect of the Bayesian approach to model selection is the summarisation of the information contained in the posterior distribution. With respect to estimation problems, this method is is routinely employed by means of punctual statistics (e.g., the posterior mean or median) plus a measure of uncertainty (e.g., credible intervals). With respect to model selection, where space being mapped probabilistically is discrete without any possible ordering, these summaries do not make sense and are not well defined. One possibility is to report the posterior mode (in this context normally called the highest posterior probability model) and its posterior probability. However, in large model spaces, posterior probabilities are small and many models share the same probability which would render this study of little use. An interesting summary are the inclusion probabilities for each potential covariate. These are defined as

$$p(x_i \mid \boldsymbol{y}) = \sum_{\{M_l:\, x_i \in M_l\}} P(M_l \mid \boldsymbol{y}), \;\; i = 1, 2, \ldots p$$

and should be interpreted as evidence (in a probabilistic scale) that xi explains the response variable. Apart from being very appealing summaries, the inclusion probabilities have a number of theoretical properties as recently studied in Barbieri and Berger (2004). We will make intensive use of these inclusion probabilities to summarise the results in our analyses.

5.2.3 *The robust prior*

The assignment of the prior distribution in model selection is a delicate issue and many papers have been written on this issue (Liang et al., 2008; Zellner and Siow, 1980, 1984; Zellner, 1986, see, e.g. []). More recently, Bayarri et al. (2012) adopt a new perspective to assign the prior density. They propose a list of criteria that should be met to drive a variable selection problem. The authors then use these criteria to propose a specific prior distribution over the parametric space, which has been proven to provide a reliable theoretical result with relatively small computational cost. This prior, known as the Robust prior, is:

$$\pi_i^R(\boldsymbol{\beta}_0, \boldsymbol{\beta}_i, \sigma) = \pi(\boldsymbol{\beta}_0, \sigma) \times \pi_i^R(\boldsymbol{\beta}_i \mid \boldsymbol{\beta}_0, \sigma) = \sigma^{-1} \times \int_0^\infty \mathcal{N}_{k_i}(\boldsymbol{\beta}_i \mid \mathbf{0}, g\,\boldsymbol{\Sigma}_i)\, p_i^R(g)\, dg, \tag{41}$$

where $\boldsymbol{\Sigma}_i = Cov(\hat{\boldsymbol{\beta}}_i) = \sigma^2\,(\boldsymbol{V}_i^t \boldsymbol{V}_i)^{-1}$ is the covariance of the maximum likelihood estimator of $\boldsymbol{\beta}_i$ with

$$\boldsymbol{V}_i = (\boldsymbol{I}_n - \boldsymbol{X}_0(\boldsymbol{X}_0^t \boldsymbol{X}_0)^{-1}\boldsymbol{X}_0^t)\boldsymbol{X}_i \tag{42}$$

and

$$p_i^R(g) = \frac{1}{2}\sqrt{\frac{1+n}{k_i+k_0}}\,(g+1)^{-3/2}1_{g\in\left(\frac{1+n}{k_i+k_0}-1,\infty\right)}, \tag{43}$$

where 1 above denotes the indicator function. Despite its involved appearance, the main advantage of this prior, apart from its reliable theoretical properties, is that it provides posterior probabilities in an analytic way (i.e., integral in 40 can be solved algebraically), which is an important computational advantage. We adopt this prior in our analyses of the GDP. Finally, we choose a prior distribution $Pr(M_i)$ for the model space. The default choice. and the one that we use, is to take all the models equally probable a priori ($P(M_i) = 1/2^p$). Other possibilities include the proposals in Scott and Berger (2006, 2010) ($P(M_i) = \binom{p}{k_i}^{-1}/(p+1)$).To implement the described variable selection approach, we use `R` package `BayesVarSel`. In particular, we use the function `GibbsBvs` to obtain approximations to the posterior inclusion probability of covariates based on the methodology in García-Donato and Martínez-Beneito (2013). Note that the number of possible models ($> 2^{32}$) is too large to allow us to compute exact posterior probabilities.

5.3 DATA AND RESULTS

5.3.1 *Data description*

This paper uses annual data for the period 1949 to 2010. We have considered the variables previously used in the literature and that are available in the case of the US, as well as additional variables that we consider suitable to capture the above-mentioned multiple transmission channels. The data and their sources are described in Appendix 1.

5.3.2 *Results*

We mainly summarise the posterior distribution with the posterior inclusion probabilities of EC and each of the potential control variables. These probabilities should be interpreted as the evidence shown by the data that a potential variable explains the GDP once the potential control variables been taken into account. The inclusion probabilities are presented for the aggregate analysis and the industrial sector in Figure 1 and for the transport and commercial sectors in Figure 2.

In the context of the literature on the nexus growth-energy consumption, the authors attempt to determine whether growth is energy-dependent and if there is a link with the direction of causality. However, this bivariate relation could be affected by many other variables. Therefore, the main focus of this paper is to assess not only if EC drives GDP but also if other potential control variables from a fairly large database could also explain GDP. Our methodology sorts the potential variables by their probability with respect to explaining GDP. We provide a detailed interpretation of these results for each of the sectors considered. To improve the readability of the study, we report only those variables for which the posterior inclusion probability is above 0.2 together with the posterior inclusion probability of the variable.

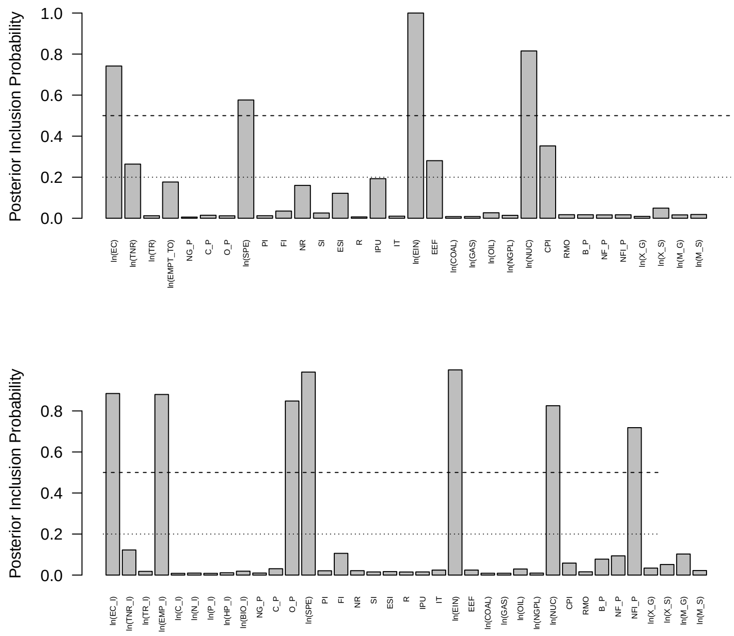


Figure 2: Inclusion probabilities for each of the potential covariates considered in the study for the aggregate study (top) and the industrial sector (bottom). The dashed line indicates a probability of 0.5 and the dotted line one of 0.2.

5.3.2.1 *Aggregate GDP results*

Concerning the aggregate GDP results, demonstrates that our results confirm the importance of **energy consumption** (**EC**) in explaining US aggregate GDP and that it has a posterior inclusion probability of 0.74. Therefore, from the application of our probabilistic model, EC and GDP variables are highly correlated highlighting the energy-dependence which is the main issue raised in the literature.

With respect to the role of the *potential control variables*, our study demonstrates that only certain candidate variables explain the aggregate GDP. We found strong evidence for energy intensity (probability 1), nuclear (probability 0.82) and spending (0.58) only. For the remainder of the variables, consumer price index (CPI) and total energy con-

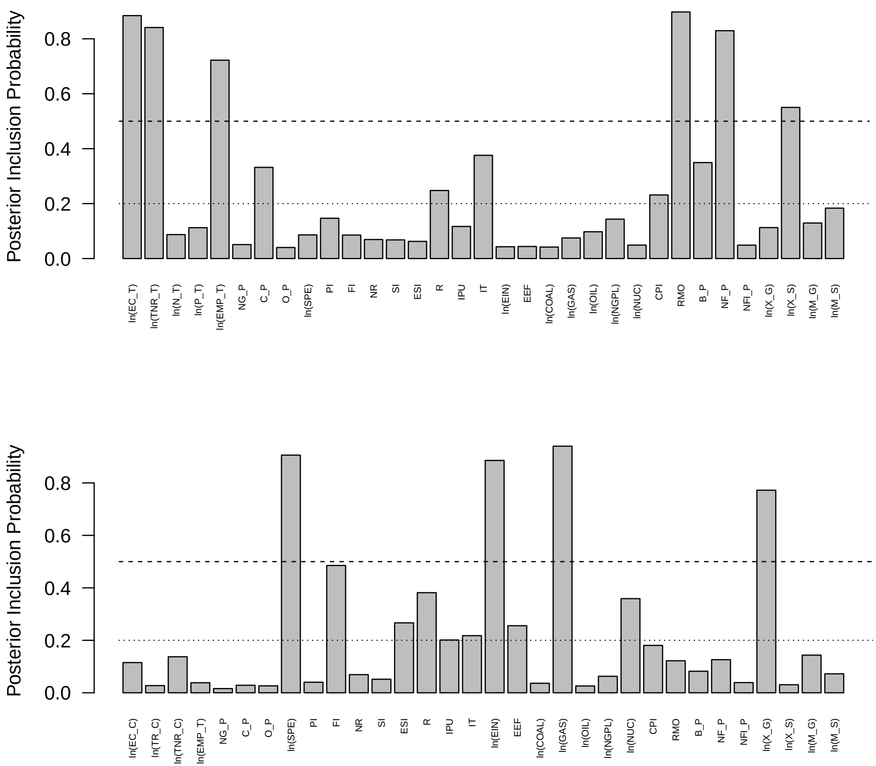


Figure 3: Inclusion probabilities for each of the potential covariates considered in the study for the transport sector (top) and commercial sector (bottom). The dashed line indicates a probability of 0.5 and the dotted line one of 0.2.

	Incl.prob.
ln(EC)	**0.74**
ln(EIN)	**1.00**
ln(NUC)	**0.82**
ln(SPE)	**0.58**
CPI	0.35
EEF	0.28
ln(TNR)	0.26

Table 28: Aggregate analysis: posterior inclusion probabilities larger than 0.2

sumption of non-renewables (TNR), we found a lower probability of inclusion. All other variables are discharged as control variables for

GDP in the aggregated study. Following is an economic interpretation of the most significant aspects of these results.

According to our probabilistic model, the variable with the highest probability of explaining GDP is *energy intensity* (*EIN*). Historically, total US primary energy consumption has been growing at a similar rate to GDP. Currently, energy consumption continues to increase (and this trend will continue according to AEO, 2010) but at a slower rate than GDP growth. This implies that there has been a progressive improvement in the US energy intensity ratio. Two factors may be responsible. First, the larger share of services in GDP and, second, the increase in efficiency in other more energy intense sectors. Our methodology has been able to capture the direct link that exists between energy intensity and GDP.

In descending order, we found that *nuclear power* (*NUC*) has the highest probability. This is not surprising considering that the US is the country with the largest installed nuclear power capacity: approximately 20% of the total amount of electricity generated comes from nuclear reactors. Since 1951, when the first reactors were installed, nuclear power has had a predominant role in the US energy mix[4]. The uncertainty with respect to oil and gas reserves, together with the scarcity of renewable energy has increased the relative importance of nuclear power. According to the IEA, a nuclear energy contribution of approximately 3.8 trillion kilowatt hours is expected in 2030, in contrast to a contribution of 2.7 trillion kilowatt hours in 2006. In the design of environmental strategies, Apergis and Payne (2009) have argued that nuclear energy plays a crucial role. This energy source can address the needs of countries in which energy demand is growing rapidly.

4 Nuclear power plays an important role in US electricity, with 101 gigawatts (GW) of capacity accounting for 19% of electricity generation in 2012 (AEO, 2013).

The next explanatory variable with a high probability, and presented in Table 2, is *public spending* (or *SPE*). There is no discussion in the literature regarding the crucial role that fiscal policies play in a country's output growth. The debate only concerns the cyclical or counter-cyclical nature of public spending. We find that this is one of the variables with a higher probability (0.8862) of explaining GDP.

5.3.2.2 *Industrial sector results*

Our study reveals that **energy consumption in the industrial sector (EC_I)** is a significant explanatory variable of GDP (inclusion probability of 0.8853). From an economic point of view, this result is logical considering that the industrial sector is the largest energy consumer; the industrial sector accounts for one third of US total energy consumption. A small group of industries use approximately 75% of the total energy of this sector, namely, chemicals, forest products, and petroleum refining industries, as well as aluminium, glass, metal casting, mining, and steel. Thus, energy efficiency policies focus on industry and manufacturing because there are still enormous opportunities for energy saving in this sector[5].

	Incl.prob.
ln(EC_I)	**0.88**
ln(EIN)	**1.00**
ln(SPE)	**0.99**
ln(EMP_I)	**0.88**
O_P	**0.85**
ln(NUC)	**0.83**
NFI_P	**0.72**

Table 29: Industrial GDP

5 One of the prime targets is the chemical industry, which uses 29% of all fuel consumed in the US industrial sector.

Among the *potential control variables* for the Industrial sector, our study shows six of them to be relevant (*EIN, SPE, EMP_I, O_P, NUC, NFI_P*), with the remainder having an inclusion probability that is below 0.2. Following is an outline of certain economic arguments for the relevance of these variables.

Energy intensity (*EIN*) is relevant according to our statistical methodology (inclusion probability of 1.0). The industry currently represents approximately 14% of US GDP, but this sector requires more than one third of total available US energy resources. Therefore, improving energy intensity would contribute to the reduction of greenhouse gases and would generate industry economic efficiency. Though the industrial sector is not the easiest sector in which to reach a high level of energy efficiency, it is a sector that provides significant returns on program investments that will directly affect energy intensity. Our methodology demonstrates the significance of energy inputs in relation to industrial output.

Public spending **(***SPE***)** is also relevant. According to the Center on Budget and Policy Priorities, the current US budget goes toward national defence and security (20%), social security (20%), Medicare, Medicaid and the Children's Health Insurance Program (CHIP,20%), safety net programs (14%) and, finally, interest on the national debt (6%). Many of these program areas are crucial for industrial output, such as supplies for the Defence department and social and medical spending that implies direct or indirect demand for industrial products. Thus, our results confirm previous findings concerning the nexus between government spending and industrial GDP (e.g., Nekarda and Ramey, 2011).

Another important variable in the explanation of industrial GDP is *industrial employment* **(***EMP_I***)**. The joint significance of *EC_I* and *EMP_I* implies that both inputs are not substitutes but complements.

This challenges the substitutability hypothesis as stated in the literature.

Oil price **(***O_P***)** also has a high probability in the explanation of the GDP path. Even if there is an abundant literature that describes the effects of oil prices in the main macro magnitudes, only a few authors have studied oil price sector effects (with respect to industry, Bohi (1989), Lee and Ni (2002), Kilian and Park (2007), Herrera (2007) and Jímenez-Rodríguez (2008)). Although different results have been found with respect to the sign and magnitude of the effect of oil on GDP, oil price has an unquestionable effect on the industrial sector because fossil fuels are the main energy source for the industry. Our methodology captures this role and assigns to oil price a high probability (0.9911) of inclusion in the industrial GDP model.

Nuclear power **(***NUC***)** is another critical control variable to take into account in the modelling of US industrial output. The relevance of nuclear power in the US energy mix is especially important in the industrial sector. The Energy Policy Act of 2005 established the development of the Next Generation Nuclear Plant (NGNP) project and has, as a primary aim, the provision of co-generated processes of heat and electricity to large industrial energy end-users. Nuclear techniques are increasingly used in industry and environmental management. The continuous analysis and rapid response of nuclear techniques, many involving radioisotopes, causes constantly available reliable flow and analytic data. This results in reduced costs from increased product quality. Although the private capital share is larger in nuclear power production, the government has actively supported an increase in capacity since the late 1990s. The government has since worked diligently to expedite approval on construction and new plant designs.

The non-financial corporation's sector productivity **(***NFI_P***)** is the last variable with a high probability captured by our model and accounts for approximately 50 percent of the GDP value for 2012. This sector excludes the activities in NF_P and contains more industrial activities. Industrial output and productivity are directly linked; Krüger (2008) claims that "structural change in the US manufacturing sector is systematically influenced by productivity change"[6].

5.3.2.3 *Transport sector results*

The variables with a posterior inclusion probability above 0.2 for the transport sector are represented in Table 4.

	Incl.prob.
ln(EC_T)	**0.88**
RMO	**0.90**
ln(TNR_T)	**0.84**
NF_P	**0.83**
ln(EMP_T)	**0.72**
ln(X_S)	**0.55**
R	0.42
IT	0.38
B_P	0.35
C_P	0.33
CPI	0.23

Table 30: Transport GDP

EC_T (***total transport energy consumption***, the sum of both renewable and non-renewable sources) and *TNR_T* (*total non-renewable energy consumption in the transport sector*) are variables with a high associated probability of explaining GDP with respect to the transport sector. The main determinants of transport demand are GDP and popu-

6 Even if manufacturing is not the only activity included in the non-financial corporate sector, they are a very significant part of it.

lation growth. According to the 2011 IEO, the US is the world's largest consumer of transportation energy. Moreover, the US energy mix for transport is imbalanced; approximately 93% of energy consumption comes from oil, the remaining 7% corresponds to natural gas and renewable sources. Despite oil consumption having reached a maximum in 2007, following the IEA a change in this trend has occurred in favour of renewable energies. This pattern of energy consumption has been captured using our methodology: although renewables data are only available since 1981, the presence of this information in EC_T is crucial. Otherwise, only total non-renewable energy consumption in transport would have been relevant.

From the remainder of the control variables, the most relevant variables are *RMO*, *NF_P* and *EMP_T* with *X_S*, all with an inclusion probability above 0.5.

The control variable with the highest probability of inclusion is *real money supply* (*RMO* hereafter). The existence of a large correlation among money supply, public expenditure and interest rates is especially relevant in a sector where both public investment and credit availability are crucial for the financing of large transport projects.

Another relevant variable to take into account in the explanation of transport is (*NF_P*), i.e., *non-business sector productivity*. This sector represents up to 77% of total US GPD. Productivity improvement is a fundamental component in business growth and internalisation and, therefore, it fosters the demand of transport sector services. This is the effect captured by our probabilistic model.

Using our statistical methodology, *transport employment* (*EMP_T*) is a significant control variable in the transport sector (inclusion probability of 0.72). According to the U.S. Bureau of Labor Statistics' 2006 to 2007 Career Guide to Industries, employment in transportation will increase by 1.1 million between 2004 and 2014 because of the introduction of new sector technologies. Moreover, SelectUsa[7] claims that international and domestic companies in this industry benefit from a highly skilled workforce and relatively low costs and regulatory burdens. Therefore, similar to the industrial sector, labour is not a substitute for EC_T or technology but a complement that explains the behaviour of transportation output.

Finally, the *exports of services* (*X_S*) is also among the critical variables. The US is the world's largest producer and exporter of services and this position will be maintained in the future because of specialisation in services with high growth potential, such as transportation services. This sector encompasses aviation, ocean shipping, inland waterways, railroads, trucking, pipelines, and intermodal services, as well as ancillary and support services in ports, airports, rail yards, and truck terminals. Therefore, transportation is a fundamental service for international trade, a role that our methodology is able to capture.

5.3.2.4 *Commercial sector results*

Table 5 summarises the results for all the variables considered in the commercial sector[8], i.e., services. The **energy consumption** (**EC_C**) is not a potential explanatory variable in the context of the commercial sector because it demonstrates a low inclusion probability (0.1152).

Concerning *potential control variables*, our study finds eleven covariantes that demonstrate a posterior inclusion probability above 0.2 for *GAS, SPE, EIN, X_G, FI, R, NUC, ESI, EEF, IT, IPU*. Certain economics

7 http://selectusa.commerce.gov/industry-snapshots/logistics-and-transportation-industry-united-states

8 The commercial sector includes the following activities: wholesale trade, retail trade, information, finance, insurance, real estate, rental and leasing, professional and business services, educational services, health care and social assistance, arts, entertainment, recreation, accommodation and food services, and government.

	Incl.prob.
ln(EC_C)	0.12
ln(GAS)	**0.94**
ln(SPE)	**0.91**
ln(EIN)	**0.89**
ln(X_G)	**0.77**
FI	0.49
R	0.38
ln(NUC)	0.36
ESI	0.27
EEF	0.26
IT	0.22
IPU	0.20

Table 31: Commercial GDP

insights for covariates with the highest probability of inclusion are as follows.

The variable with the highest probability of explaining commercial output is *natural gas* (*GAS*). Following the EIA most of the energy consumption in this sector is devoted to space heating, lighting, cooling and, more recently, the food service industry. Natural gas represents approximately 40% of total energy use in this sector because it is an extremely efficient, economical energy source for heating all types of commercial buildings, as well as an energy source for large commercial food preparation establishments.

According to our methodology, employed *SPE* also has a high probability of being an explanatory variable for commercial sector GDP (0.91). Such a wide and diverse sector that includes education, health care and social services has a clear and direct link to the government and its activities.

Additionally, *energy intensity* (*EIN*) has a significant associated probability. A priori, we may expect the service sector to use a smaller amount of energy input for the production of a single unit of output in comparison to the other sectors. Our approach is able to capture the fact that the commercial sector is less energy-dependent than the other productive sectors.

Finally, our probability approach establishes that *goods exports* (X_G) are also a relevant variable for commercial GDP. The reason for this result is likely because exports imply the use of a variety of commercial services, such as insurance, finance and other professional and business services. Although it is beyond the scope of this paper, finding a significant contribution of exports to the model can be taken as evidence of the potential relevance of the Pollution Haven Hypothesis.

5.4 CONCLUSIONS

There is abundant empirical literature that is focused on whether energy consumption is a critical variable in the explanation of economic growth. Even with an established nexus to the positive among researchers, no conclusive results have been obtained. The evolution of this literature is composed of efforts that mainly attempt to solve the problems and criticisms that were found in earlier studies. In this context, we classify these problems into two areas: first, those that analyse the bivariate relationship EC-GDP and that neglect many potential channels affecting this relationship; second, those that introduce other control variables that are considered determinants in the EC-GDP nexus. This second area of the literature, which is broader in scope, has limitations that are derived from a selection process of the control variables. These variables are frequently chosen following the subjective economic rationale of the authors.

Our main contribution attempts to overcome the variable limitations by implementing a robust statistical approach that selects the covariate variables that explain GDP. The outcome of our methodology is the inclusion of the probability for each variable from a large group of potential explanatory variables. Although covariate selection must be prior to cointegration or causality testing, this has been neglected in the empirical literature.

Our results are twofold. First, the empirical evidence confirms the prior expectation that energy consumption is a critical variable to understanding the path of GDP because the energy consumption variable is relevant for all sectors with the exception of the commercial sector only. Moreover, the results highlight the importance of the SPE and EIN variables in modelling the relationship between GDP and energy consumption because they have a high probability of inclusion in three of the four models we study. It is equally important to note that our probabilistic model captures the relevance of total energy consumption, i.e., the joint role of renewable and non-renewable energy sources. This study recognises the substantial share that renewable energy has in US output growth. Otherwise, only total non-renewable energy consumption would have associated a high inclusion probability.

Second, the results highlight the importance of a disaggregate analysis of GDP because of the different explanatory variables that are relevant for the different sectors that we consider, namely, the commercial sector, and transport and industry. In fact, nuclear energy production and employment are critical variables for only two sector outputs but for these sector are quite relevant.

Finally, the results reveal that the decision making of policy-makers is complex. The interaction between variables demonstrated in this paper indicates that policymakers not only have to design policy that focuses on reducing energy consumption, but they must also take into account other important macro variables. Additionally, this complexity is also a result of sector differences that prevent the design of a general policy.

APPENDIX A

Table 32: Datasources Energy consumption- GDP nexus

VARIABLES	MEASURE	DATA SOURCE
GDP	Real = VA/VAPI millions dollars.	US Bureau of Economic Analysis (http://www.bea.gov/)
Employment (EMP)	Full time and part time employees in millions.	US Bureau of Economic Analysis (http://www.bea.gov/)
Energy Consumption (EC)	Billions BTU	US Energy Information Administration (http://www.eia.gov/)
Consumption of: Total Energy Non-Renewable (TNR), of Total Energy Non-Renewable (TR), Coal (C), Natural Gal (NG), Petroleum (P), Hydroelectric Power (HP), Biomass (BIO)	Billions BTU	US Energy Information Administration (http://www.eia.gov/)
Energy Prices: Natural Gas Price (NG_P), Coal Price (C_P)	NG_P: Natural Gas Wellhead Price.C_P: Dollars per Short Ton.All the prices are in chained (2005) dollars, calculated by using gross domestic product implicit price deflators.	US Energy Information Administration (http://www.eia.gov/)
Oil Price (O_P)	Real Oil Price (in $/bbl.). Prices are based on historical free market (stripper) prices of Illinois Crude as presented by IOGA. Prices are adjusted for Inflation to December 2012 prices using the Consumer Price Index (CPI-U) as presented by the Bureau of Labor Statistics	http://inflationdata.com/Inflation/Inflation_Rate/Historical_Oil_Prices_Table.asp
Spending (SPE)	Government Spending (Real). Total Spending -total$ Billions 2005.	www.usgovernmentspending.com/

Gross Fixed Capital Formation: Private Investment, Fixed Investment (FI), No Residential Investment (NR), Structure Investment, Equipment & Software Investment (ESI), Residential Investment (R), Public Investment (IPU), Private Investment (PI), Structure Investment (SI), Total Investment (IT).	Investment in Fixed Assets and Consumer Durable Goods. Billions of dollars.	US Bureau of Economic Analysis (http://www.bea.gov/)
Money Supply (RMO)	Real money. Reserve Assets, SDR millions.	OCDE
Energy Intensity (EIN)	Primary Energy (billion btu) / GDP in billions of chained 2005 dollars	Primary Energy Consumption: EIA US Energy Information Administration (http://www.eia.gov/).GDP: US Bureau of Economic Analysis (http://www.bea.gov/)
Energy Efficiency (EEF)	GDP in billions of chained 2005 dollars / Primary Energy Consumption (billion btu)	Primary Energy Consumption: EIA US Energy Information Administration (http://www.eia.gov/).GDP: US Bureau of Economic Analysis (http://www.bea.gov/)
Source of energy production: (COAL), Natural Gas (GAS), Crude Oil (OIL), Natural Gas Plant Liquids (NGPL), Nuclear (NUC)	Total energy Production. Billion Btu.	http://www.eia.gov/
Consumer Price Index (CPI)	All Urban Consumers - (CPI-U) US city average 1982-84=100	US Department Of Labor Bureau of Labor Statistics
Business sector Productivity (B_P), No farm business sector Productivity (NF_P), No financial corporate sector Productivity (NFI_P)	Output per hour. Type of Measure: Index, base year2005=100	http://www.bls.gov/data/
Exports: Goods Exports (X_G), Services Export (X_S) Imports: Goods Imports (M_G), Services Imports (M_S)	Output per hour. Type of Measure: Index, base year2005=100. Millions of dollars, seasonally adjusted	US Bureau of Economic Analysis (http://www.bea.gov/)

The table shows which variables have been incorporated into the analysis in each of the four models: Aggregate, Commercial, Industrial and Transport. The subscripts C, I and T refer to the variable is measures for that particular sector.

Despite its appeal, the Bayesian implementation is not without significant difficulties that are likely to preclude its broad use in economic studies. These difficulties are associated with the assignment of the prior distribution and the necessity to approximate the posterior distribution because of the intractable size of the set of entertained models (which grows with the number of potential explanatory variables). We therefore circumvent these difficulties by using the `R` package `BayesVarSel` García-Donato and Martínez-Beneito (2013), which is a user-friendly interface for the methodology proposed in the papers Zellner and Siow (1984); Zellner (1986); Zellner and Siow (1980); Liang et al. (2008); Scott and Berger (2010, 2006); Bayarri et al. (2012); García-Donato and Martínez-Beneito (2013).

Covariate	Sector			
	Aggregated	Commercial	Industrial	Transport
ln(GDP)	✓	✓(_C)	✓(_I)	✓(_T)
ln(EC)	✓	✓(_C)	✓(_I)	✓(_T)
ln(TNR)	✓	✓(_C)	✓(_I)	✓(_T)
ln(TR)	✓	✓(_C)	✓(_I)	– (NA's)
ln(EMP)	✓(EMPT_TO)	✓(EMP_T)	✓(EMP_I)	✓(EMP_T)
ln(C)	–	–	✓(_I)	– (NA's)
ln(N)	–	–	✓(_I)	✓(_T)
ln(P)	–	–	✓(_I)	✓(_T)
ln(HP)	–	–	✓(_I)	–
ln(BIO)	–	–	✓(_I)	–
NG_P	✓	✓	✓	✓
C_P	✓	✓	✓	✓
O_P	✓	✓	✓	✓
ln(SPE)	✓	✓	✓	✓
PI	✓	✓	✓	✓
FI	✓	✓	✓	✓
NR	✓	✓	✓	✓
SI	✓	✓	✓	✓
ESI	✓	✓	✓	✓
R	✓	✓	✓	✓
IPU	✓	✓	✓	✓
IT	✓	✓	✓	✓
ln(EIN)	✓	✓	✓	✓
EEF	✓	✓	✓	✓
ln(COAL)	✓	✓	✓	✓
ln(GAS)	✓	✓	✓	✓
ln(OIL)	✓	✓	✓	✓
ln(NGPL)	✓	✓	✓	✓
ln(NUC)	✓	✓	✓	✓
CPI	✓	✓	✓	✓
RMO	✓	✓	✓	✓
B_P	✓	✓	✓	✓
NF_P	✓	✓	✓	✓
NFI_P	✓	✓	✓	✓
ln(X_G)	✓	✓	✓	✓
ln(X_S)	✓	✓	✓	✓
ln(M_G)	✓	✓	✓	✓
ln(M_S)	✓	✓	✓	✓

6

SUMMARY, CONCLUSIONS AND FURTHER RESEARCH

Greenhouse gases are emitted locally around the different countries in the world, but their negative effects, resulting in the very worrying climate change, are an international problem since the fight to reduce them requires international treaties and solutions. Thus to effectively address the environmetal damage is critical to involve as many countries as possible in reducing emissions.

These treaties and agreements are designed by, for example, one of the most important institution in the fight against climate change, the United Nations Convention on Climate Change (UNFCCC), which has the primary objective of stabilizing and reducing the levels of gas emissions in the largest possible number of countries. Nonetheless, for these agreements to be as multilateral and global as they can, developing countries have to find the environment protection policies to be fair and equal. An aspect considered to be a key factor in this is the convergence in their levels of emissions among developed countries, since they are all in a similar stage of development, relatively superior to that of developing countries, which can then afford to apply emissions reduction policies through the investment in cleaner technologies and in turn specialize in less polluting economic sectors.

We analyze, in chapter II, the existence of convergence among 22 OECD countries and observe that said countries actually diverge. This fact is aggravated when studying the environmental performance of countries using the United States as a benchmark. The results show that the countries analyzed are found to converge with the US, that is, they are converging with the world leading country in emissions levels.

Two kinds of conclusions can be inferred from such study. On one hand, conclusions of economic policy, and on the other, those referring to methodology. In regards to the implications of political economy it is clear that a much stronger effort is necessary from developed countries and that the so far implemented policies have not had the expected results, as evidence shows that their emissions levels are not stable. Thus it becomes very complicated to ask emerging countries - which development is just beginning and which have the incumbent need to generate wealth in more contaminating sectors and with more polluting machines – a depletion in their emissions when richer countries do not comply with these requirements.

On what concerns the methodology used in this branch of literature related to convergence, our analysis in chapter II shows the existence of several works that they are not robust on the convergence assessment among countries. We can observe in different cited articles in the previous literature how a critical previous step is neglecting in the analysis of convergence, that is, the stochastic nature of the original series of emissions. If this analysis is omitted and country's emissions and the emissions average of the studied countries are originally stationary, an assessment of convergence using this series lacks statistical significance, which in turn can lead to misleading conclusions concerning crucial policy decisions aimed at combating Climate Change.

The second key feature worthy of mention from a methodological point of view in this chapter is the criticism we offered in relation to the use of the Carlino & Mills measure to study convergence, which consists in using the average of the sampled countries as a reference. Although the study incorporates a sample of countries at a certain level of heterogeneity in their economic level and development, an average which includes countries such as Luxembourg and the United States will inevitably be characterized as a high dispersion measurement. In fact, as demonstrated in chapter II, when we apply the Carlino & Mills measure with the United States as benchmark we end up concluding that a convergence exists in regard to the United States, as US substantially bias the results. Therefore, searching for an alternative measure to analyze convergence of emissions in a time series framework, rather than the average of the studied countries, is something of great interest in a future analysis within this branch of literature.

Finally within chapter II, we introduced in detail the main contribution of this thesis, the importance of considering nonlinear methodology in the study of variables such as emissions and the GDP. Although recently different authors have used nonlinear methods to draw conclusions within environmental economics literature, examples were very limited when this dissertation was started.

Back to the political economy implications that have been highlighted throughout the chapter II, the need to develop more strict policies for environmental issues becomes significant for better results to fight global warming. However, the main problem for implementing climate change mitigation measures is the uncertainty about how these measures could affect economic growth. Therefore, it becomes critical to understand whether these variables, emissions and the GDP, are related, and if they are, which of the two causes effects over the other or if we face a relation of interdependence. The articles in this field of literature are based on the methodological concepts of causality and cointegration to provide an answer to this issue.

In chapter III, we verified that within a sample of 10 OECD countries, for 7 out of them the variables emissions and economic growth were cointegrated, so we went on to study causality between them. The empirical evidence is clear in favor of the interdependence between emissions and growth. As we have done, we will differentiate consequences in economic policy from those which are strictly methodological and of literature research.

Concerning policy implications, the interdependence shown by both variables implies that a decrease (or an increase) in the allowed emissions levels would entail a decrease (or an increase) in economic growth. Nevertheless, to assess the level of dependence between emissions and the GDP, it is necessary to carry out an individualized and detailed research of each country to understand the sign of the relation. This detailed analysis is beyond the scope of this dissertation, but that is a crucial modelization that remains outstanding in this thesis for a future research studies. If the limitation of emissions have negative effects on the growth path, policymakers would have a very critical challenge, as it implies that energy acts as a limiting factor for growth. Therefore in order to design strategies for prevention Climate Change, it must be taken into account that the policies with effects on the reduction and stabilization of emissions will also generate consequences for the GDP.

Regarding methodology, again, as we have done in chapter II, we compare the results after employing linear tests with those obtained using nonlinear methodology, remaining clear that the results depend on the chosen strategy, yet another time. Our contribution, besides the adoption of nonlinear methods, consists in overcoming the criticism in not analyzing whether the variables are cointegrated before studying the causality between them. The existence of cointegration guarantees causality in one of two ways, but not vice versa. Thus, directly analyzing causality might lead to an error interpretation, such as if the gap between the series is not stationary causality analysis lacks statistical significance.

While previously we concentrated on studying the importance of understanding the behavior of the emissions and the GDP variables in order to design effective environmental policies, in chapter IV we focused on what has been the performance on one of the most important among these policies, the Kyoto protocol. Our research was concretely centered on EU-15 countries. Base on the long term relation between energy consumption and the GDP, we will assess if they are cointegrated. Methodologically, the contribution we bring into this analysis is to identify a stronger concept of cointegration, stochastic cointegration instead of just deterministic cointegration. If the GDP shows a growing trend but the level of emissions is not proportional, the hypothesis of a long-term relation must be rejected. For these countries where cointegration does not exist, as the GDP and emissions values are not stable, accomplish with the Kyoto targets entail higher costs. This is what is reached for countries such as Austria, Denmark, Italy, the Netherlands and Portugal.

In regards of economic implications, policymakers must take into account that there are in fact certain countries that are meeting, or are on the right path to, the objectives established by Kyoto, while others, those listed before, that will have to make a greater effort to reduce emissions in order to satisfy the requirements. Subsequently, an improvement in environment conservation can be distinguished, but it is still not as close as expected to the ultimate goal, sustainable development.

The need for the modelization of both variables in future studies that was mentioned earlier can also be of great interest for the evaluation of its trends. This way, we could find, in the cases where stochastic cointegration does not exist, which variable grows disproportionately in relation to the other.

After analyzing by univariate approach the stochastic nature of emissions series in chapter II, and later in a bivariant framework in chapter III and IV, studying the relation between emissions and economic growth, finally, we considered which variables could provide information and were therefore also important in the modelization of this bivariant relationship. The main criticism in the literature referring to the GDP-emissions relation is focused on the macroeconomic nature of both variables which are, thus, conditioned by the effects of a myriad of variables that wouldn't be studied by employing a bivariant analysis. So far empirical proposals to overcome this criticism is based on the incorporation in the analysis GDP-emissions nexus some control variables selected by the authors subjectively.

In chapter V, we provide a probabilistic model to identify whether it is energy consumption that explains the GDP or if there are other macroeconomic variables that help us better understand this relation that we presume to be exposed to countless interactions with other economic variables. Therefor, in this dissertation, instead of analyzing what occurs with specific pre-selected variables, we statistically select from a large group of possible candidates those with the higher probability of contributing to the explanation of the GDP. Thus this analysis allows us to recognize if it is necessary and important to take other variables into account in the modelization of the GDP-emissions relationship. We do this for the United States and the study confirms what we were expecting, the critical importance of energy consumption in the explanation of the GDP. Additionally, it is very interesting to see how the public consumption and the energy intensity are two crucial variables in the American economic growth. Lastly, we must also highlight the different results in explanatory variables for each economic sectors.

These results show the arduousness that the policy makers face in order to design measures in favor of sustainable development, since to understand the effect that enviromental preventive measures have on economic growth they must not only concentrate on the consequences that a decrease in energy consumption has, but they also have to pay attention to how the GDP interacts with macroeconomic variables such as the Public Expenditure or the Energy Intensity. Furthermore, the complexity of the matter increases as we found that general measures cannot be applied within a country, but they must be specific to each economic sector.

In conclusion, the challenge that economic and environmental policymakers embark in pursuit of sustainable development is a difficult task, given the need for cooperation to be as global as possible in order for the adopted measure to truly be effective and not only simultaneously address the idiosyncratic characteristics of each of the committing country, but go a step further to design these policies in each generator of wealth sector.

Regarding methodology, environmental economics literature is relatively recent but growing very fast. Nonetheless, the limitation of existing data related to emissions as well as environmental performance, has forced some investigations to be less robust than it would be desirable statistically. This fact causes that the literature accept certain methodologies or to be somewhat permissive in the selection of methodologies used, such as, panel methods due to the limited availability of data, or even some studies skip steps in methodological procedures based on these limitations. Despite all this, we must be able to gain rigour in this kind of studies in the next decades, and produce results that could help the design of policies to fight against the very serious issue of climate change and achieve the desired sustainable development at world level.

7

RESUMEN, CONCLUSIONES Y FUTURAS INVESTIGACIONES

Los gases de efecto invernadero se producen de manera local en los distintos países del mundo, sin embargo, sus efectos negativos que resultan en el preocupante cambio climático son un problema internacional ya que la lucha por reducirlos requiere de acuerdos y soluciones internacionales (para que las medidas que sean planificadas tengan efecto).

Acuerdos que, por ejemplo, diseña uno de los organismos más importante en la gestión contra el cambio climático, the United Nations Framework Convention on Climate Change (UNFCCC), que tiene como objetivo primordial la estabilización y reducción de los niveles de emisiones del máximo número de países posibles. Sin embargo, para que estos acuerdos sean lo más multilaterales o globales que se puedan, los países en vías de desarrollo tienen que considerar que las políticas de protección medioambiental son justas y equitativas. Para ello, un aspecto que se considera clave es la convergencia en sus niveles de emisiones entre los países desarrollados, ya que todos ellos se encuentran en un estadio de desarrollo similiar y relativamente superior a los países emergentes pudiendo, de esta manera, permitirse políticas de reducción de gases mediante la inversión en tecnología más limpia y a su vez por la especialización en sectores económicos menos contaminantes.

En el capítulo II analizamos la existencia de convergencia entre 22 países OCDE y observamos que dichos países divergen. Este hecho se ve incluso agravado cuando se estudia el comportamiento medioambiental de las naciones respecto a Estados Unidos y se determina que los países de la muestra se encuentran convergiendo en emisiones con el país que es lider mundial en emisiones.

Dos tipos de conclusiones podemos extraer de dicho estudio, por un lado, conclusiones de política económica y, por otro lado, aquellas referentes a la metodología. En lo que concierne a las implicaciones de política económica es evidente que es necesario un esfuerzo mucho mayor del que se ha realizado hasta ahora por parte de los países desarrollados y que las políticas implementadas, hasta hoy, no han tenido los resultados esperados, ya que sus niveles de emisiones no son estables, no convergen. De esta manera resulta muy complicado exigir a los países cuyo desarrollo está iniciándose recientemente y que necesitan generar riquezas en sectores productivos más contaminantes y con maquinarias más polusivas, una reducción en sus emisiones cuando los países ricos no cumplen con una de las claves medioambientales, la estabilización de los niveles de emisiones.

En lo que concierne a la metodología usada en esta rama de la literatura relacionada con la convergencia, nuestro análisis en el capítulo II muestra como exiten numerosos trabajos que son poco robustos en la evaluación de la existencia o no de convergencia entre los países. En varios artículos citados en la literatura previa podemos observar como en ellos se obvia un paso previo crítico antes del análisis de convergencia, que es la naturaleza estocástica de las series originales de emisiones. El no realizar este paso puede llevarnos a concluir erróneamente que los países se encuentran convergiendo cuando verdaderamente no es así, ya que puede que la naturaleza estocástica de las series analizadas, emisiones de un país y media de emisiones de los países muestrales, sea en ambos casos estacionaria, por lo que estudiar la convergencia entre ellas carece de sentido estadístico.

El segundo aspecto a destacar a nivel metodológico de este capítulo es la crítica que realizamos al uso de la medida de Carlino y Mills para estudiar la convergencia, que consiste en utilizar como referencia la media de los países de la muestra. Pese a estudiar un grupo de países con un cierto grado de heterogeneidad respecto a su nivel económico y de desarrollo, la media de la muestra de estos países donde se incluyen países como Luxemburgo y Estados Unidos se caracteriza por ser una medida de elevada dispersión. De hecho, como hemos comprobado en el capítulo II, cuando el lugar de hacer uso de la medida de Carlino and Mills lo haemos con Estados Unidos como benchmark se termina concluyendo que existe convergencia respecto a Estados Unidos, ya que dicho país sesga enormemente los resultados. Por tanto, la búsqueda de una medida alternativa a la media de los países estudiados para poder analizar la convergencia de emisiones con series temporales es algo de mucho interés en un futuro análisis dentro de esta rama de la literatura.

Por último en el capítulo II introducimos de manera argumentada la contribución principal de esta tesis, la importancia de considerar la metodología no lineal en el estudio de variables como emisiones y PIB. Pese a que actualmente ya existen varios autores que lo consideran fundamental basarse en métodos no lineales para extraer conclusiones en esta literatura de economía medioambiental, al inicio de esta tesis doctoral eran escasos los ejemplos que pudimos encontrar.

De vuelta a las implicaciones de política económica evidenciadas en el capítulo II, se impone la necesidad de elaborar políticas más contundentes en materia medioambiental que conlleven mejores y mayores resultados en la lucha contra el cambio climático. Sin embargo, el mayor problema para tomar este tipo de medidas es la incertidumbre de cómo van a afectar al crecimiento económico. Por ello, resulta clave conocer si ambas variables, emisiones y PIB están relacionada, y en caso de estarlo, cúal de ellas es la que origina efectos sobre la otra o si estamos ante una relación de interdependencia. Los artículos de esta literatura se basan en los conceptos metodológicos de cointegración y causación para dar respuesta a lo anterior.

En el capítulo 3 en una muestra de 10 países OCDE comprobamos que para 7 de ellos las variables emisones y crecimiento económico están cointegradas y por lo tanto pasamos a estudiar que ocurre con la causalidad. La evidencia empírica es contudente a favor de la hipótesis de que existe interdependencia entre ambas. Como hemos realizado con anterioridad diferenciaremos aquellas consecuencias de política económica de las que son puramente metodológicas y de investigación de la literatura.

A nivel de toma de decisiones políticas la interpendecia mostrada por ambas variables significa que una reducción (un incremento) en el nivel de emisiones permitido conllevaría una disminución (un incremento) del crecimiento económico. Sin embargo, para conocer el grado de dependencia entre emisiones y PIB es necesario hacer un estudio individualizado y detallado de cada uno de los países para conocer el signo de la relación, análisis que está fuera del alcance de esta tesis, pero que es una modelización necesaria que ha quedado pendiente en este trabajo para estudio futuro. Si la limitación de emisiones produjera un empeoramiento de la senda de crecimiento, estaríamos ante un caso muy importante ya que se pone de manifiesto que la energía actúa como factor limitante del crecimiento. Por tanto a la hora de trazar estrategias de prevención y cuidado medioambiental hay que tener en cuenta que el diseño de políticas con efectos en la reducción y estabilización de emisiones generarán también efectos en el PIB.

En lo referente a la metodología, nuevamente, al igual que hacíamos en el capítulo II, comparamos los resultados tras emplear tests lineales y aquellos que tienen en cuenta la no linealidad, quedando comprobado las diferencias obtenidas en función de la forma funcional escogida. Nuestra contribución además del uso de métodos no lineales, es sobrepasar la crítica de no analizar previa a la causalidad entre las variables, si ambas están o no cointegradas. La existencia de cointegración garantiza la causalidad en alguno de los dos sentidos, sin embargo, no ocurre lo mismo en sentido contrario. Por tanto, el análisis directamente de causación puede conllevar a error de interpretación como que existe causalidad entre las variables y sin embargo la diferencia entre estas no es estable de manera que el análisis de causación no tiene sentido.

Mientras que anteriormente hemos estudiado la importancia de conocer el comportamiento de las variables emisiones y PIB a la hora de diseñar las políticas medioambientales para que sean efectivas, en el capítulo IV nos planteamos como ha sido el rendimiento de una de esas políticas más importantes que los países han firmado hasta el momento, el protocolo de Kioto. Concretamente lo estudiamos para los países EU-15. Basándonos en la relación a largo plazo entre el consumo energético y el PIB comprobaremos si ambas están cointegradas. Metodológicamente la aportación que hacemos en este análisis es comprobar un concepto de cointegración más robusto, es decir, la cointegración estocástica y no sólo la determinista. Si el PIB muestra una tendecia creciente pero el nivel de emisiones no es proporcional, la hipótesis de relación a largo plazo debe ser rechazada. Estos países donde no existe cointegración, ya que las series del PIB y de emisiones no son estables, les costará relativamente mucho más cumplir con los objetivos de Kioto. Esto es lo que se obtiene para los países de Austria, Dinamarca, Italia, Holanda y Portugal.

En lo que se refiere a política económica, los encargados del diseño de medidas de conservación medioambiental deben tener en cuenta que hay determinados países que sí que están cumpliendo, o están en la senda correcta de hacerlo, con los objetivos establecidos por Kioto, y sin embargo hay otros, los enumerados anteriormente, que tienen que realizar un mayor esfuerzo en la cuantía de reducción de emisiones para adaptarse a lo exigido. Por tanto, se aprecia un avance en la mejora medioambiental, pero aún no es tan completo como lo que se esperaba para conseguir el objetivo último, el desarrollo sostenible.

La necesidad de modelización de ambas variables en futuros trabajos que fue expresada anteriormente puede ser de gran interés también para el evaluación de sus tendencias. De esta manera podíamos comprobar en los casos que no existe cointegración estocástica, qué variable crece de manera desproporcionada respecto a la otra.

Tras haber analizado de manera univariante en el capítulo II la naturaleza estocástica de las series de emisiones, seguidamente de forma bivariante en los capítulos III y IV estudiando la relación entre emisiones y crecimiento económico, finalmente, nos planteamos qué variables pueden proporcionar información y por ello son también importantes a la hora de modelizar esta relacion dual (bivariante). La principal crítica en la literatura referente a la relación emisiones-PIB tiene que ver con que se trata de un estudio de dos variables macroeconómicas y que por tanto pueden estar condicionadas por los efectos de multitud de variables que no serían estudiados escogiendo un análisis bivariante. Las propuestas empíricas hasta el momento para sobrepasar estas críticas consisten en introducir en el análisis variables seleccionadas por los autores de manera subjetiva.

En el capítulo V, se propone un modelo probabilístico para identificar si el consumo energético es el que explica el PIB o existen otras variables macroecómicas que nos ayudan a entender mejor esta relación que a priori presumimos que está expuesta a multitud de interacciones con otras variables económicas. Por ello, en esta tesis, en lugar de analizar que ocurre con determinadas variables seleccionadas de antemano, seleccionamos estadísticamente aquellas que con mayor probabilidad contribuyen a explicar el PIB identificando si es necesario e importante tener en cuenta en la modelización de la relación emisiones-PIB otras variables. Esto lo hacemos para EEUU y el resultado pone de manifiesto lo que podíamos esperar a priori que es el consumo energético como una variable crítica en la explicación del PIB. Adicionalmente resulta muy interesante comprobar como el consumo público y la intensidad energética son dos variables cruciales a la hora de entender el crecimiento económico estadounidense. Por último, también debe debemos de destacar los diferentes resultados en cuanto a variables explicativas se refiere cuando desagregamos por sectores.

Queda latente la dificultad con la que se encuentran los decisores de política a la hora de diseñar medidas a favor del desarrollo sostenible ya que para comprobar el efecto que las mismas tienen en el crecimiento económico no sólo deben atender a las consecuencias que tienen las reducciones en el consumo energético sino que adicionalmente deben prestar atención como interactua el PIB con variables macroeconómicas como el Gasto Público o la Intesidad Energética. Además, la complejidad aumenta al comprobarse que no se puede realizar medidas de carácter general dentro del mismo país, sino que deben de ser específicas para cada sector ya que la influencia de las variables difieren según de cúal se trate.

Concluyendo, el reto al que se enfrenta los decisiores de política económica y medioambiental en busca del desarrollo sostenible es una tarea ardua, dada la necesidad de que la cooperación sea lo más global posible para que verdaderamente las medidas adoptadas sean efectivas y simultáneamente se atiendan las características idiosincráticas no sólo de cada uno de los países que tengan que comprometerse sino que hay que ir un paso más allá para realizar estas políticas en cada sector generador de riqueza.

En relación a la metodología, la literatura de economía medioambiental es relativamente reciente pero con un crecimiento muy acelerado. Sin embargo, la limitación de datos existentes relacionados con emisiones así como rendimientos en cuanto a comportamiento medioambiental se refiere, ha generado que las investigaciones en ocasiones sean poco robustas y por lo tanto en la literatura se acepte metodologías o se sea permisivos ante estudios que utilizan, por ejemplo, metodología de panel por la escasa disponibilidad de datos, o incluso algunos que se saltan pasos previos en procedimientos metodológicos basándose en la escasez de datos suficientes. A pesar de ello, en las próximas décadas debemos poder ganar en rigor en los estudios y producir resultados que ayuden al diseño de políticas de lucha contra el grave cambio climático y consigamos alcanzar el tan deseado desarrollo sostenible a nivel mundial.

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