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Re-examining CO_2 emissions. Is the assessment of convergence meaningless?

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Castellón (Spain)

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Abstract

This paper re-examines CO2 emissions in 22 OECD countries over the period 1870–2006. It contributes to the field of environmental economics trying to clarify the possible sources of the mixed evidence on CO2 emissions convergence. To this end we employ a detailed methodological strategy. First we start with standard linear tests as the ones proposed by Ng and Perron (2001). Then, using the Lee and Strazicich (2003) tests, we take into account the possible existence of structural breaks in the series. Finally, we apply a non-linear test within a smooth transition autoregressive (STAR) framework proposed by Kapetanios et al. (2003). The empirical evidence provided by our methodological strategy suggests that the original per capita CO2 emissions for the largest span, from 1870 to 2006, are stationary, so that to continue with the assessment of convergence in this context would not be adequate. However if we consider instead the period 1950-2006, per capita CO2 emissions are in a non-stationary local regime. Thus, in this case we proceed with the study f convergence. Bearing in mind plausible nonlinearities, CO2 emissions convergence is assessed using two versions of the Kapetanios et al. (2003) test, and conclude that there is no robust convergence among these 22 OECD countries.

Keywords: CO2 emissions, stationarity, non linear test, smooth transition, convergence

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Abstract

This paper re-examines CO_2 emissions in 22 OECD countries over the period 1870–2006. It contributes to the field of environmental economics trying to clarify the possible sources of the mixed evidence on CO_2 emissions convergence. To this end we employ a detailed methodological strategy. First we start with standard linear tests as the ones proposed by Ng and Perron (2001). Then, using the Lee and Strazicich (2003) tests, we take into account the possible existence of structural breaks in the series. Finally, we apply a non-linear test within a smooth transition autoregressive (STAR) framework proposed by Kapetanios et al. (2003). The empirical evidence provided by our methodological strategy suggests that the original per capita CO_2 emissions for the largest span, from 1870 to 2006, are stationary, so that to continue with the assessment of convergence in this context would not be adequate. However if we consider instead the period 1950-2006, per capita CO_2 emissions are in a non-stationary local regime. Thus, in this case we proceed with the study of convergence. Bearing in mind plausible nonlinearities, CO_2 emissions convergence is assessed using two versions of the Kapetanios et al. (2003) test, and conclude that there is no robust convergence among these 22 OECD countries.

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1 INTRODUCTION

The effects of greenhouse gases increase 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, the empirical literature is abundant, so that several studies can be found on dominant gases, namely carbon dioxide (CO_2), methane (CH_4), oxygen, nitrogen (N_2O), hydrochlorofluorocarbons (HCFCs), chlorofluorocarbons (CFCs), and sulfur hexafluoride (SF_6). The reason that explains this extensive literature is that they are the main cause of global warming. In fact, Kyoto's Protocol goal is to reduce these six gases. However, the vast majority of the studies focus on carbon dioxide, which makes sense according to the prediction by the Intergovernmental Panel on Climate Change (IPCC, hereafter), that concluded in 2001 that CO_2 is the most important of the gases, explaining about two thirds of the radioactivity resulting from greenhouse gases, which worsens the greenhouse effects. Additionally CO_2 is the gas with the longest life cycle, remaining in the atmosphere around a hundred years. Thus, it is considered to be responsible for at least 61% of the global warming expected in the next 100 years IPPC (1990).

Therefore, understanding the pattern displayed by CO_2 is a challenge that lies ahead for both politicians and international organizations responsible for ensuring environment protection. Indeed the success in the fight against climate change is crucially dependent upon a good analysis of CO_2 emissions. But why is the assessment of CO_2 emissions crucial?

First, identifying the historical path and the current trend of CO_2 emissions allows scientists to forecast properly the level of atmospheric concentration. This in turn implies that policy makers know the required quantity of CO_2 emissions that should be reduced, a crucial issue to design an efficient policy action. The above methodologically involves examining whether the effect of a shock on the CO_2 series is temporary and mean reverting, or if the series have a non-stationary behavior. If stationarity is assumed, it will be temporary, so that it will not have a lasting influence. Thus, when some time elapses the series will revert to its mean value.

McKitrick and Strazichic (2005) point out another issue, for which understanding CO_2 behaviour is crucial. In particular, the scenarios used by the IPCC, "which are of great influence on global warming predictions", may vary considerably in their projections depending on the assumptions about the stability or the stationary pattern of per capita emissions.

Second, since the pioneering work by Grossman and Krueger (1995) many empirical studies have provided results that support a positive correlation between a country's level of development and its level of CO_2 emissions. This has given rise to the so called Environmental Kuznets Curve (EKC) literature, which postulates that in the early stages of growth "environmental demand" increases as a result of per capita income rising. However, later, when development has reached a critical point, demand begins to decrease with higher income, thus an U-inverted functional form exists.

Evidence in favor of economic convergence has been presented by Barro and Sala-i-Martin (1991),(1992) and Evans and Karras (1996), among others, so, if the shape of the emissions-income relationship holds, emissions convergence must occur. In this line of research, List (1999) is one of the first papers about emissions convergence that applies two indicators of environmental quality across U.S.A. regions over the period 1929-1994 to the assessment of whether income convergence also implied air pollutant emissions convergence. Some evidence in favor of convergence was obtained using univariate unit root tests. Hereupon several studies have been carried out attempting to find empirical evidence on environmental convergence among groups of countries.

Although the global level of emissions is the most important target and therefore spatial convergence of CO_2 may not seem important[1], however to achieve success in environmental policy as defined by the Kyoto Protocol, convergence becomes a crucial issue.

Kyoto's essential multilateral agreement is not exempt from debate and the geographical distribution of CO_2 would help making progress in the two main controversial issues surrounding it. The first one is the allocation of emission rights to each country; the second one is the fact that those developing countries with higher growth rates are not committed to abide by any target. Since the analysis of the CO_2 series behavior is the first step in any convergence study, this paper contributes to shed some light in this issue.

The current emission quotas are based on the levels of greenhouse gases that the signatory countries

[1] Because this is negligible from the point of view causing harmful effects on the environment

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 the allowances should be allocated. The survey of Bodansky (2004) collects 40 proposals, 10 of them being assigned according to the per capita emissions scheme.

The allowance scheme is not trivial, since a very important redistribution of wealth might take place among the signatory countries, as shown in Aldy (2006). Aldy compares two distribution systems: one based on historical emissions (scheme prevalent at the moment) 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 (2005) claims 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, as well as Aldy (2006), share the concern about the allowance system and potential wealth's transfers. She reminds that fossil fuels distribution and consequently CO_2 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 rights assignment would lead to large adjustment costs and thus wealth transfer among countries.

Hence for policymakers, it is crucial important to know whether indeed the countries that signed the Kyoto's protocol are in a convergent path in their per capita emissions. Therefore this paper instead of treating convergence at length is more focused on the steps before convergence assessment, so it contributes to this field since, an assessment of the time series properties of the variables involved is needed previous to the convergence analysis.

Concerning the complex issue of how to involve the larger developing countries in the process of cutting their emissions, there are different positions. The United States exemplifies the attitude of those who have rejected the ratification of the Kyoto Protocol waiting for emergent countries like China or India to be imposed 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 CO_2 than the developed ones.

On the other side there are lobby groups and other country groups, especially the developing ones, advocating 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 CO_2 emissions, that is, the EKC relationship.

The importance of reconciling positions is reflected in the GCI (1998) study, which assures that to involve the countries in a global agreement, the emissions have to be allocated equally among all countries in a way that it can be both achievable and seen as fair by all. So that convergence among developep countries would lead to a larger number of countries, especially emergent ones, committed to a common strategy.

In light of all the aforementioned reasons, it is undeniable that CO_2 convergence deserves special attention. However, despite the different empirical techniques that have been used for its assessment the results are not conclusive. This may stem from two main reasons.

First, that the individual variables of CO_2 emissions are directly assumed to be non stationary, instead of testing it, prior to the convergence analysis. If this first step is overlooked when the original CO_2 series are stationary and countries have different per capita CO_2 levels, there is no possibility of convergence among them, so that trying to test for convergence is irrelevant.

On the other hand, the techniques applied in the majority of the cases are linear. Thus, this may also explain some of the inconclusive results that have been found.

Accordingly, this paper contributes to the existing literature trying to clarify these two possible sources of the mixed evidence on CO_2 emissions convergence. To make explicit the necessary analysis of the original CO_2 emissions series, we employ a detailed methodological strategy. First, we start using standard linear tests as the ones 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 apply a non-linear test, namely the one proposed by Kapetanios et al., 2003. This preliminary stage allows us to check whether the series are non-stationary, thus determining if studying convergence makes sense.

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. Thus we employ a nonlinear methodology instead of a linear one, which is commonly the chosen technique in most studies. A possible reason to explain the non-linear behavior of this variable may be related to the first source of CO_2 emissions, which is economic activity.

GDP is used as a proxy for economic activity. Through economic cycles, recessions are followed by expansions and between them periods of stabilization occur. Therefore, if the main source of CO_2 release into the atmosphere exhibits cyclical behavior then a similar functional form is likely be found in the CO_2 emissions pattern.

Concerning the nonlinear behavior of GDP, apart from Beechey and Österholm (2008), within the environmental literature Lee and Chang (2009) support this hypothesis and argue that: "relative CO_2 emissions are directly related to the use of energy, which is an essential factor for both production and consumption". Furthermore, Lanne and Liski (2004) use linear methodology in their work and attribute their "confusing findings" to this technique, so that they finally recommend applying a non linear methodology in future analysis.

The functional form of the EKC is another reason why the linear methodology seems not to be suited to capture the behavior of CO_2 emissions. The majority of the empirical studies have used quadratic polynomial models to give support to the hypothesis of a long-run relationship between emissions and income levels, since a U-inverted form is assumed.

This hypothesis involves, first, 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 the income level reaches a critical point, the emissions begin to decrease. Thus, this emission pattern that suffer 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 crisis, have affected CO_2 emissions. We highlight the work Lanne and Liski (2004) since together with the exact timing of potential breaks, they perform 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, but also in Lanne and Liski (2004), 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, economic activity, the main source of

CO_2 release, does not cease suddenly. In practice a delay exists between a shock and the reaction of the economic agents. Thus, instead of an instantaneous change among regimes, transition occurs gradually.

From this evidence, a Smooth Transition Autoregressive (STAR) model could be suited to capture emissions behavior, as this model allows for deterministic components with a gradual rather than an instantaneous adjustment and nonlinear dynamics in CO_2 emissions.

In sum this paper re-examines the dynamics of CO_2 emissions attempting to assess whether they are stationary. The purpose is therefore twofold: first, a good understanding of the underlying data generating process of carbon dioxide emissions; second, the results obtained in this first stage will verify if the CO_2 emissions convergence study can be carried out, since in the event of a stationary behavior of the individual country series, if they are at different levels, there would be no possibility that these countries converge. Accordingly, conclusions drawn from studies of convergence would lead to misguided decisions.

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 PREVIOUS RESULTS

To the best of our knowledge, the majority of the empirical studies do not reach to clear conclusions regarding convergence in CO_2 emissions. The majority of the authors analyze convergence via unit root test using a measure proposed by Carlino and Mills (1993). These authors test 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 CO_2 emissions relative to the average of per capita CO_2 emissions for each country "i", i.e.:

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

Tab. 1: PREVIOUS EMPIRICAL STUDIES

AUTHOR/S	DATA BASE	SAMPLE	METHODOLOGY	RESULTS
List and Strazicich (2003)	WDI (2004)	21 OCDE COUNTRIES 1960-1997	LINEAL. MEASURE: Carlino and Mills (1993) TEST: Im et al. (2002)	CONVERGENCE
Lanne and Liski (2004)	CDIAC	16 OCDE COUNTRIES 1870-1998	LINEAL. 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	LINEAL. 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	LINEAL. MEASURE: Carlino and Mills. TEST: Im et al. (2002)	DIVERGENCE
Westerlund and Basher (2008)	CDIAC	28 OCDE COUNTRIES 1870-2002	LINEAL. MEASURE: Evans (1998). TEST: Three panel: Phillips and Sul (2003), Bai and Ng (2004) and Moon and Perron (2004).	CONVERGENCE
RomeroÁvila (2008)	OECD (2004)	23 OCDE COUNTRIES 1960–2002	LINEAL. 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	LINEAL. MEASURE: Carlino and Mills TEST: Unit root test proposed by Sen (2003)	CONVERGENCE
Lee and Chang (2008)	WDI (2004)	21 OECD COUNTRIES 1960-2000	LINEAL 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	LINEAL. MEASURE: Carlino and Mills. TEST: Panel unit root test developed by Carrion-i-Silvestre et al. (2005)	CONVERGENCE

Using this measure, the authors test 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 shock but the series are stationary, quite the opposite effects occurs: CO_2 converges towards the sample average once the effects of the shock disappear. In other words, a unit root in the log relative series supports divergence and the rejection of a unit root implies a stationary or mean reverting behavior.

In an attempt to fill the gap between the empirical literature about pollution and income correlation (EKC), 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, Pesaran and Shin (2002, IPS) finding that spatial convergence has taken place. Additionally they carried out cross-section regressions, as an alternative approach to assess convergence. This entails analyzing cross-section correlation between the initial level of output and the subsequent growth rates for a group of countries. Obtaining a negative correlation implies convergence, since countries with low initial levels of output are growing faster than those that come from higher output levels. Using this technique List and Strazicich (2003), (LS henceforth), also present evidence in favor of convergence among a group of countries.

Lanne and Liski (2004) use unit root tests allowing for structural breaks and 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 the industrialized countries. The earliest phase is dated at 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, taking place a transition from coal to gas and oil use. The third phase would start after the oil crisis of the seventies, where the main source of emissions release is fossil fuel, causing a reduction in the CO_2 trend.

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

Similar to Lanne and Liski (2004), Lee et al. (2008a) performed a unit root test allowing for a simultaneous break in the slope and in the 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 LS. 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 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 that 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 LS, Aldy considers that the dissimilitudes in the findings are not inconsistent. It simply means that stochastic convergence so far has been limited.

Barrasi et al. (2008) analyze CO_2 convergence for 21 OECD countries between 1950 and 2002, giving support to the conclusions of Aldy. Actually, from the comparison with LS (2003), and using the same methodology and a similar span, in contrast to the clear evidence of convergence obtained by LS (2003), Barrasi et al. (2008) find that 11 countries exhibit a unit root. This casts doubts on the degree of emissions convergence among OECD countries.

Barrassi et al. consider that the key to such differences is the criterion used to select the lag length. While LS (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-Perron (2001) for each auxiliary regression. This criteria 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 diverge, and refers to overparameterisation to explain his discrepancy with LS (2003).

Westerlund and Basher (2008) emphasize the differences between their study and those of LS (2003) and Aldy (2006). The most significant one is that they use panel data tests to examine and explain the high persistence of the CO_2 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 are focused on countries that follow policies of environmental protection (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 would display each country.

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 it is 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), they argue that Carlino and Mills (C&M, hereupon) definition is a weak measure of convergence, since the emissions of two countries could be diverging deterministically. Over the period of 1870-2000 and using a sample containing 28 countries, 12 of them emerging, Westerlund and Basher (2008) find convergence in per capita emissions across these countries.

Similarly, Romero-Ávila (2008) and Lee and Chang (2009) apply 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 work of Westerlund and Basher (2008), since they both try to discern common from idiosyncratic elements.

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

As a general conclusion about the empirical evidence on emissions convergence, the findings are not unanimous. However it is remarkable the fact that except for Aldy (2006) and Lanne and Liski (2004) the stationarity analysis of the original CO_2 series is not presented in these papers. 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 aforesaid reveals that it is crucial to determine if the original series are stationary prior to the assessment of convergence.

3 METHODOLOGICAL STRATEGY

In the rest of the paper we are going to focus on the analysis of the original CO_2 series, aiming at finding the key behind many inconsistent results concerning convergence. To that 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. Accordingly, to make sure 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 able to capture breaks in the slope or in the 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 the nonlinearities with a unit root. Therefore, we finally implement the test proposed by Kapetanios et al., 2003.

3.1 STANDARD LINEAR TESTS

Ng and Perron (1995) proposed the MZ_t^{GLS} tests which is a modified versions of Z_t (originally designed by Phillips and Perron (1989,)), based upon Generalized Least Squares (GLS, hereafter) detrended data. Elliot et al. (1996) proposed 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.

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

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

Ng and Perron (2001) argue 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 the BIC tend to select a truncation lag that is too low. This can provoke Type I error (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 problems, they suggest using instead a modified AIC (MAIC) with a penalty factor that is sample dependent.

3.2 LINEAR TESTS ALLOWING FOR STRUCTURAL CHANGE

Although the Ng and Perron (1995) have good properties, the omission of structural breaks can provoke a severe loss of power. To prevent it, in a second stage we have applied unit root tests that allow for structural breaks. We have chosen a 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 $\phi = 0$.

3.3 NON LINEAR UNIT ROOT TESTS

Kapetanios et al., (2003, KSS hereafter) proposed a unit root test against a globally stationary ESTAR process. As it is 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 it 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 reparameterised 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 a 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 the proposed by Ng and Perron might fail to reject the null of nonstationarity since they only test for the value of ϕ. It might happen, therefore, that linear tests mistake the presence of non-linearity with the existence of a unit root.

The KSS test goes a step further in order to test wether 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, Kapetianos 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):

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

Table 3 shows the results from the application of the standard model selection criteria for the number of augmentations p, such as the Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), Hannan-Quinn (HQ) and Modified Akaike Information Criterion (MAIC).

4 DATA AND EMPIRICAL RESULTS

4.1 DATA

We have computed the tests using data for 22 OECD countries[2]. 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 splitted it into sub-periods to allow both, a direct comparison with previous studies summarized in 1, as well as to know whether the CO_2 emissions depend on the occurrence of significant events. Thus, we allow for three sub-periods between 1870 and 2006.

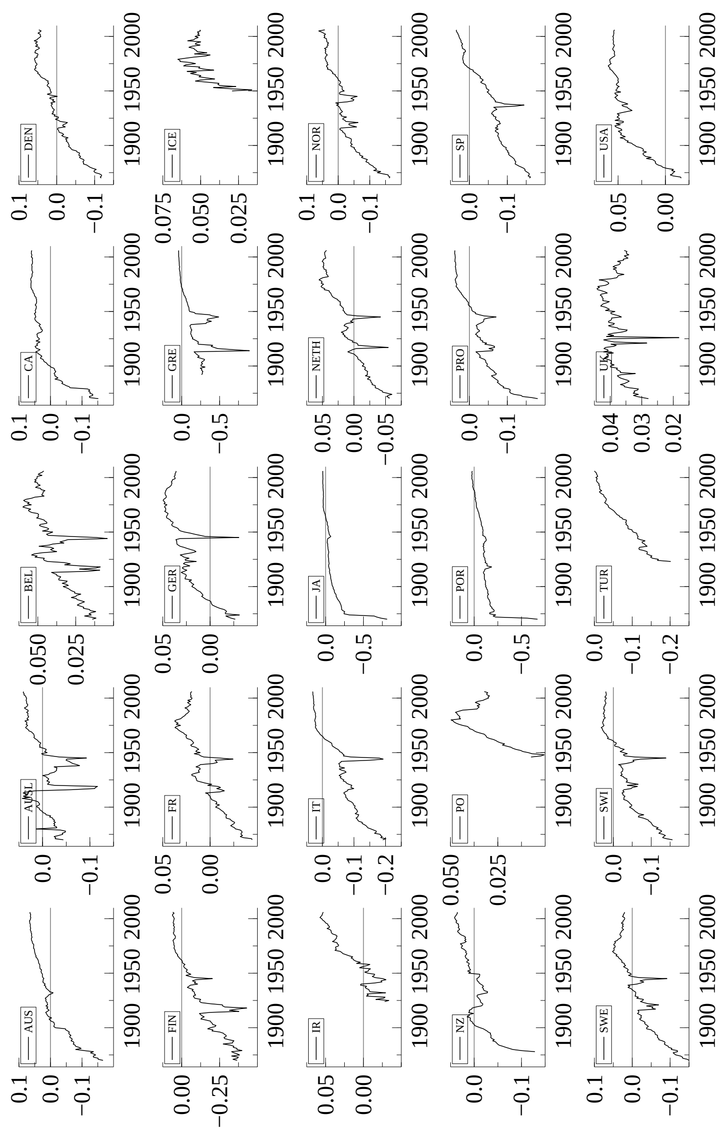
Apart from the whole sample, the first sub-period that we consider starts in 1870, a date that has been selected to avoid the potential effects of outliers at the beginning of the database. As pointed out by Lanne and Liski, 2004, around 1870 most of the developed countries were check the early years of industrialization. The effects of the first wave of industrialization is considered to have finished around 1900, so that another sub-sample starts with the century. Moreover, up to the 50's may be a suitable time for capture potential effects upon CO_2 of extraordinary events such as the WWII, the oil crisis, as well as the highest economic growth of developed countries, which results in a sharp increase of their CO_2 emissions.

4.2 RESULTS

In this section we present the empirical evidence that we have obtained following the same order described in the methodological section. 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 2 summarizes the number of countries that are found to be I(0). The outcome is the expected one: independently of the particular sub-sample chosen, the majority of the CO_2 series can be considered non-stationary. However, this

[2] 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.

Fig. 1: CO_2 emissions per capita



Tab. 2: SUMMARY OF THE LINEAR TESTS

TOTAL SERIES I(0)

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 present the results of the tests suggested by Lee and Strazicich (2003). "L" and "S" mean that the break occurs in the level and in the slope respectively. The number of changes are in parentheses. See section 6 for details.

The asymptotic null critical values for these tests are detailed on Table 9 in Annexes.

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

evidence is not sufficient to conclude in favor of I(1) variables, since both, the presence of nonlinearities in the CO_2 data and possible structural changes make the standard linear tests such as Ng and Perron (2001) biased towards nonstationarity.

Figure 1 shows graphs of 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. Therefore we must ensure that the series 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 in the power of the ADF unit root test. Even if the Ng and Perron tests have better power properties that 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. Similar findings have been obtained by Lanne and Liski (2004) or Lee et al. (2008a).

Thus, in order to improve the specification of the tests, we should allow for changes in the deterministic components of the CO_2 series. The reasons behind the use of this specification is that structural breaks are not only related to the different stages in the countries' industrialization process, but also with the occurrence of extraordinary events.

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 in the level. Later, Lee and Strazicich (2003) extend the test to capture up to two changes, which are described in Table 2 as "L" and "S" when a break occurs in the level and in the slope respectively, where the number of breaks are in parentheses.

The importance of the possible structural changes is highlighted, since, in 1870, 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. Although our purpose is not to estimate the exact moment of the breaks, we present in table 10 the breaks clustered according to the span where they happened. Roughly speaking most of the breaks occur from 1925 onwards.

The number of countries originally stationary is high enough to alert us about the convenience of studying convergence emissions. At this point we should decide whether the study of convergence is meaningful depending on how many of the original CO_2 series are I(0). If the majority of the variables are I(0) to test for convergence using the definition of Carlino and Mills (1993), as most studies used it, will be meaningless or, at least, result in outcomes that can lead to misleading inferences.

The methodology proposed by Carlino and Mills 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 average of CO_2 emissions per capita and conclude that the evidence in favor of stationarity increases, as the unit root test is more suited to the pattern displayed by CO_2 emissions. Therefore applying Carlino and Mills measure what we would be doing is 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 the stationarity analysis varies significantly if we do not account for the structural changes in CO_2 emissions. Then, we can also ask ourselves what would happen if in addition to allowing for changes in the deterministic structure we modify the functional form so that the model can capture nonlinearities in CO_2 emissions.

This is achieved by using smooth transition autoregressive (STAR) models, which can help us to overcome two potential problems that arise from use of the linear test. The autoregressive structure of

Tab. 3: KSS NONLINEAR TEST

TOTAL SERIES I(0)				
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

Ng-Perron (2001) and Lee and Strazicich (2003) tests is linear. Thus if the series of CO_2 exhibit non-linear dynamics, these tests fail to assess the order of integration of the variables. Using the Kapetanios et al. (2003) test we can accomodate a more suitable alternative hypothesis: the variables can be in reality non-linear although globally stationary.

The results of the KSS non-linear test are reported in Table 3. Note that depending on the chosen criteria for the lag order in the auxiliary regression, the number of countries for which we can reject the null hypothesis of the unit root differs slightly.

Kapetanios et al. (2003), Sercu et al. (1995a) or Michael et al. (1997b) show 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 comparison of the results for the first three sub-periods in Table 2 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 2 for the longest sample size, the Ng and Perron test reject the null hypothesis only for 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 at least for 9 out of 21 countries.

The fact that the MZ_t^{GLS} fails to reject the null in the presence of nonlinearities is also evident if we consider the 1900-2006 sub-period. Even the number of countries found stationary is larger than from 1870 to 2006. For instance, independent of the criterion chosen is the AIC, the BIC or the HQ 52 per cent of the countries are stationary, a percentage sufficiently large to consider that the CO_2

emissions are I(0)[3]. However for the sub-period 1950-2006, it is remarkable the drop in the proportion of I(0) countries that have been found . Specifically using the MAIC criterion the number of countries significantly decreases considerably. This fact may reveal that from 1950 onwards the CO_2 emissions are in a local non-stationary regime. As we have shortened the time period, the historical information of the process is lost, therefore it is more difficult that the mean reversion of the series after a shock occurs.

Note that one of the main features of the STAR models is that they allow the process within a particular regime be nonstationay but, nonetheless, the overall process could be stationary, so the loss of information encumber one of the critical advantages of these models. Therefore, the 56 observations between 1950 and 2006 do not allow the series to be globally stationary. 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 it has been reported in Table 10.

Going back to Table 1, where we report previous empirical papers and results, in seven of them the samples begin after 1950. Assuming non-stationarity of the original CO_2 series from the 50's onwards allows us to continue with the convergence study.

Once we have checked the CO_2 behavior, now the evidence allows us to assess the existence of convergence. This ensures that policy conclusions concerning environmental policies that could be taken are based on robust econometric results. For this purpose, we analyze, using the KSS test, the existence of convergence between these 22 OECD countries using two different measures.

The first of them is the above mentioned definition proposed by C&M, as shown in equation (11). The results are presented in Table 4 below, where each column corresponds to the selection of lags according to different criteria. Using the first three criteria, there are 7 countries[4] that converge using the AIC, while they are 9 and 8 cases according to both the BIC[5] and HQ[6] criteria respectively. However, the number of countries that are converging is lower[7] if we chose the MAIC as the lag order selection criterion.

[3] see table 3

[4] Australia, Ireland, Netherlands, New Zealand, Norway, Sweden and Switzerland.

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

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

[7] 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.

Tab. 4: CONVERGENCE ACCORDING TO THE DEFINITION OF CARLINO AND MILLS

TOTAL SERIES I(0)				
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

To summarize, after concluding that the variables are I(1) from 1950 to 2006, we have analyzed the existence of convergence based on the C&M criterion. Moreover, we have taken into account possible nonlinearities in the CO_2 emissions series. As in previous literature, there is evidence in favor of convergence but it is not conclusive.

As can be seen in the Table 4 we have also checked the result using the C&M measure for the period 1870-2006. Accordingly this results would lead us to conclude that 17 out of 20 countries are converging. However since the CO_2 emissions average is stationary this outcome can not be interpreted as convergence.

Therefore, this paper contributes to clarify two possible sources of the mixed evidence on convergence. On the one hand to omit the analysis of the order of integration of the variables previous to continuing with the study of convergence. On the other hand, the fact that previous studies have not taken into account the presence of potential non-linearities in the CO_2 emissions. The conclusions we have reached is that, according to the C&M convergence criterion, there is not strong evidence of convergence among the 24 OECD countries we have studied.

At this point arises a new issue which challenges our above conclusion: Is the C&M definition the most appropriate way to assess convergence?. The truth is that this measure, based on the CO_2 emissions average, 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.

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

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

Table 5 summarizes the results obtained using this new measure, that are very similar to the previous ones. This is due to the large weight of the US emissions in the sample mean.

Tab. 5: CONVERGENCE THE US AS A BENCHMARK

TOTAL SERIES I(0)				
Series start at	AIC	BIC	HQ	MAIC
1950-2006	**13/23**	**14/23**	**15/23**	**9/23**

The election of the U.S. as a benchmark is a wholly consistent measure, considering the above mentioned relationship between GDP and emissions. Moreover, the US is the world's largest economy and acts as a leader in international growth patterns. However, at this point, we must consider also the economic implications of concluding that the countries analyzed are converging towards the U.S., the major per capita polluting country. Thereby, policy makers should take this evidence into account, because it seems that the more developed countries are not in the right direction in the fight against Climate Change.

5 CONCLUSIONS

So far the results of the empirical studies on CO_2 emissions convergence are not conclusive: they provide mixed evidence. However prior to assessment of convergence it is necessary to know whether the original CO_2 series behave as a stationary process. If this analysis is omitted and the emissions are, instead, originally stationary, the assessment of convergence using this series might be meaningless, which in turn can lead to misleading conclusions concerning crucial policy decisions against Climate Change.

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

Accordingly, this paper contributes to the field of environmental economics clarifying two possible sources of the mixed evidence on CO_2 emissions convergence. On the one hand to overlook, or at least not make explicit, the necessary analysis of original CO_2 emissions series, as a preliminary step to be taken to know if the series are non-stationary. To this end we conducted 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 applying the tests designed by Lee and Strazicich (2003). Finally we apply a non-linear test, specifically, the one proposed by Kapetanios et al. (2003).

The second 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 going through a recession period.

Fluctuations over time between periods of growth and those of decay have an impact on the CO_2 emissions level. Shifts between these periods of expansion characterized by higher CO_2 release, and recessions with a lower level of economic activity, which cause fewer emissions, occur gradually instead of instantaneously. This sort of dynamics is well captured by switching-regimen models, allowing the economic agents to react once time elapses, which can be captured by a transition function. Especially suited are the Smooth Transition Autoregressive (STAR) models.

Consequently, in this paper we examine the CO_2 emissions behavior 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 splitted in three different sub-periods. At the same time the sub-samples help us to determine the effects of outstanding events on CO_2 emissions.

Once we conduct our strategy to test for CO_2 behavior, the empirical results obtained for the the two widest spans, that is from 1870 to 2006 and from 1900 to 2006, show clear evidence in favor of stationarity. 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, the 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 found by List and Strazicich, where the majority of the breaks are located in the latter span, from the 50's. As the variables are I(1), the study of convergence (implying the stationarity of the difference between the two variables) is fully relevant.

For this reason we use the definition of 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 C&M measure we re-evaluate the countries comparing them with the US arriving at 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 50's because this means that nowadays the CO_2 emissions levels 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 increase steadily their CO_2 emissions levels. This will entail that some developing countries can be discouraged to constrain their emissions since industrialized countries are not able to follow a stable path of emission levels. The emerging countries, based on certain notions of equality and responsibility, expect that developed countries, which mainly have contributed to the atmospheric concentration of pollution, should make a greater effort to prevent climate change.

Additionally most rights distribution schemes are based on emissions per capita assuming the countries' income convergence. However, the analysis of 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 such as Aldy (2006) argues in his work.

Finally, many climate models are designed assuming convergence across countries. Policy makers 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 accordingly upon these controversial turning points.

6 ANNEXES

Tab. 6: 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	-1.4094	1899	-3.4689	1904	-1.5506	1899 1931	-4.3349	1913 1937
AUSL	-2.43	4	-4.0389**	1916	-3.991	1915	-4.2701**	1916 1929	-6.16**	1914 1948
BEL	-3.02**	2	-4.4553***	1982	-4.6467**	1982	-4.6474***	1950 1982	-5.3239*	1939 1970
CA	-0.4	3	-0.8256	1887	-3.5518	1904	-0.877	1887 1922	-4.8702	1883 1905
DEN	-0.63	2	-2.3259	1991	-3.3269	1981	-2.5776	1895 1991	-5.5602*	1915 1965
FIN	-3.3**	1	-3.4635*	1945	-4.0676	1965	-3.712*	1926 1947	-4.708	1912 1925
FR	-1.53	2	-2.9236	1980	-3.5734	1984	-3.0409	1980 1993	-5.0923	1939 1973
GER	-1.71	2	-3.1376	1906	-3.8853	1894	-3.2554	1887 1906	-5.2318	1912 1954
GRE	-2.67	1	-3.1037	1949	-3.7199	1949	-3.1962	1908 1949	-4.6572	1937 1949
IT	-1.94	6	-4.7794***	1946	-5.0328**	1946	-5.195***	1916 1946	-6.3933***	1941 1963
JA	-0.72	6	-1.3631	1893	-3.9818	1888	-1.392	1893 1920	-4.7756	1883 1898
NETH	-2.95*	2	-4.3286***	1969	-4.4863**	1959	-4.4205**	1969 1991	-6.5101***	1939 1970
NZ	-1.33	3	-1.651	1950	-3.4508	1920	-1.8318	1913 1950	-4.7428	1913 1938
NOR	-1.28	7	-3.5367*	1939	-3.7775	1920	-3.7874*	1939 1989	-4.8927	1914 1966
POR	-2.3	5	-1.6284	1917	-3.7971	1883	-1.7001	1917 1937	-5.6327**	1883 1941
SP	-2.06	2	-3.1527	1916	-3.8745	1932	-3.4545	1916 1932	-5.6693**	1932 1972
SWE	-1.22	6	-2.7859	1979	-3.6211	1982	-2.9347	1898 1979	-4.846	1915 1969
SWI	-1.45	6	-2.9624	1920	-3.4309	1920	-3.2042	1893 1920	-4.5978	1915 1962
UK	-0.63	4	-4.3498***	1979	-5.5815***	1981	-5.1215***	1893 1979	-8.9193***	1918 1971
USA	-0.94	11	-1.4564	1887	-3.7377	1902	-1.598	1887 1906	-4.5258	1917 1940
$\overline{CO}_{2t}$	-1.63	1	-2.2432	1920	-2.971	1916	-2.4528	1920 1944	-3.754	1915 1962

	MZ_t^{GLS}	**L(1)**	**L(1) S(1)**	**L(2)**	**L(2) S(2)**
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 2. They are extracted from Ng and Perron (2001) and Lee and Strazicich (2003)

Tab. 7: LINEAR TESTS 1900-2006

1900	MZ_t^{GLS}		**L(1)**	**TIME**	**L(1) S(1)**	**TIME**	**L(2)**	**TIME**	**L(2) S(2)**	**TIME**
AUS	-2.48	1	-2.5246	1931	-2.4999	1961	-2.7946	1931 1953	-4.1683	1929 1980
AUSL	-2.04	4	-3.4638*	1915	-4.5753**	1945	-3.6985*	1915 1947	-5.5203*	1914 1948
BEL	-2.81*	2	-3.8815**	1950	-4.1605	1967	-4.0536**	1926 1950	-4.5251	1939 1970
CA	-1.97	2	-2.2988	1912	-3.1649	1921	-2.3552	1912 1934	-4.0857	1923 1969
DEN	-1.4	2	-2.6242	1996	-3.7585	1965	-2.8804	1959 1996	-5.2504	1957 1969
FIN	-2.78*	1	-3.0917	1945	-3.7481	1921	-3.3637	1919 1945	-4.4135	1912 1923
FR	-2.01	2	-2.6285	1948	-3.2239	1966	-2.7633	1948 1996	-4.0314	1939 1973
GER	-2.86*	2	-3.6046**	1949	-4.1851*	1950	-3.7815*	1949 1959	-5.1326	1949 1975
GRE	-2.71	1	-3.0586	1949	-3.5765	1949	-3.1292	1918 1949	-4.6235	1937 1949
IT	-1.77	6	-4.5311***	1946	-5.209***	1946	-5.0297***	1935 1946	-7.0012***	1946 1970
JA	-2.04	3	-2.5007	1948	-2.5704	1960	-2.7159	1948 1960	-4.781	1943 1970
NETH	-2.82*	2	-3.7147**	1969	-4.423*	1961	-3.8852**	1959 1969	-5.87**	1939 1970
NZ	-2.1	3	-2.2806	1912	-3.3081	1932	-2.4678	1912 1951	-4.7655	1917 1950
NOR	-1.92	8	-3.6357**	1969	-3.9781	1959	-3.8768**	1937 1969	-5.2642	1939 1970
POR	-1.08	5	-2.0397	1917	-3.8319	1944	-2.2296	1917 1937	-4.3846	1915 1961
SP	-1.7	2	-2.7861	1969	-4.1118	1938	-3.0321	1916 1969	-6.7581***	1934 1972
SWE	-1.83	3	-2.8415	1945	-3.6003	1965	-2.9138	1917 1945	-4.426	1940 1969
SWI	-2.16	2	-2.9225	1920	-3.6633	1953	-3.2237	1920 1955	-5.5476*	1941 1968
UK	-1.17	6	-5.0846***	1950	-5.8412***	1950	-6.1419***	1950 1979	-8.0514***	1918 1971
USA	-1.77	12	-2.7312	1912	-3.0983	1921	-2.9249	1923 1981	-4.2689	1919 1940
$\overline{CO_{2t}}$	-2.3	1	-2.4348	1916	-3.0646	1949	-2.6132	1916 1947	-4.6658	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 2. They are extracted from Ng and Perron (2001) and Lee and Strazicich (2003). Grecia data starts at 1983 and New Zealand at 1878. Turkey data starts at 1923 and Ireland at 1924.

Tab. 8: 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	-3.234	1978	-1.5408	1931 1953	-4.4532	1929 1980
AUSL	-0.83	1	-1.3662	1979	-4.5186**	1976	-1.6303	1932 1953	-5.7899**	1930 1980
BEL	-1.14	1	-1.7137	1982	-3.1404	1970	-2.065	1933 1953	-4.7145	1931 1980
CA	-1.39	1	-1.4828	1969	-2.8836	1969	-1.7722	1934 1953	-3.8595	1932 1980
DEN	-0.91	1	-1.6309	1991	-3.5924	1969	-1.9193	1935 1953	-4.3963	1933 1980
FIN	-0.65	1	-1.1528	1958	-4.7817**	1972	-1.3781	1936 1953	-5.3805*	1934 1980
FR	-0.61	1	-1.0019	1975	-3.6237	1976	-1.1797	1937 1953	-5.6695**	1935 1980
GER	-0.24	1	-0.5862	1975	-2.3662	1976	-0.7024	1938 1953	-4.1614	1936 1980
GRE	-0.78	4	-0.8065	1970	-3.5682	1973	-0.8637	1939 1953	-6.1234**	1937 1980
IR	-1.21	1	-2.315	1958	-4.4813**	1967	-2.8028	1940 1953	-5.3771*	1938 1980
IT	-0.83	2	-0.7621	1975	-4.1628	1970	-0.9032	1941 1953	-5.19	1939 1980
JA	-0.42	1	-0.7692	1975	-4.1104	1969	-0.9461	1942 1953	-4.4447	1940 1980
NETH	-0.77	1	-1.3841	1969	-3.6782	1970	-1.537	1943 1953	-4.1841	1941 1980
NZ	-2.78	1	-2.7605	1983	-3.3815	1985	-2.9378	1944 1953	-4.446	1942 1980
NOR	-1.04	1	-1.8348	1989	-2.9747	1968	-2.2895	1945 1953	-4.0391	1943 1980
POR	-1.04	1	-1.7152	1999	-2.7133	1967	-1.8436	1946 1953	-4.2108	1944 1980
SP	-0.95	1	-1.5525	1969	-2.3052	1980	-1.7581	1947 1953	-4.2056	1945 1980
SWE	-0.71	2	-0.7281	1959	-2.8938	1969	-0.8181	1948 1953	-5.6587**	1946 1980
SWI	-0.25	1	-0.8012	1959	-6.3863***	1970	-0.8698	1949 1953	-7.4719***	1947 1980
TUR	-1.14	1	-1.6917	1961	-2.9416	1972	-2.0421	1950 1953	-3.8701	1948 1980
UK	-1.67	1	-1.7996	1979	-3.7165	1972	-2.2272	1951 1953	-4.2299	1949 1980
USA	-1.61	1	-1.7737	1975	-2.9811	1968	-1.8737	1952 1953	-4.4867	1950 1980
$\overline{CO}_{2t}$	-0.67	2	-0.8413	1975	-4.23*	1970	-0.9921	1953 1953	-5.0353	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 2. They are extracted from Ng and Perron (2001) and Lee and Strazicich (2003).

Tab. 9: CRITICAL VALUES

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 LS 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.

Tab. 10: TIME OF THE BREAKS

SPAN	1870-2006				1900-2006				1950-2006			
Periods	**L(1)**	**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

Tab. 11: NON LINEAR TEST KSS 1870-2006 and 1900-2006

	1870									1900							
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	**AUS**	-1.18	1	-0.94	0	-0.94	0	-0.94	0
AUSL	-5.45***	2	-5.45***	2	-5.45***	2	-4.18***	0	**AUSL**	-6.36***	2	-6.36***	2	-6.36***	2	-4.34***	0
BEL	-2.04	2	-2.41	0	-2.41	0	-2.04	2	**BEL**	-1.79	2	-2.13	0	-2.13	0	-1.79	2
CA	-2.64*	4	-2.31	0	-2.31	0	-1.23	1	**CA**	-1.87	0	-1.87	0	-1.87	0	-1.58	2
DEN	-0.79	2	-0.79	2	-0.79	2	-0.79	2	**DEN**	-1.3	2	-1.86	0	-1.3	2	-1.3	2
FIN	-2.56	0	-2.56	0	-2.56	0	-2.56	0	**FIN**	-2.52	0	-2.52	0	-2.52	0	-2.52	0
FR	-1.48	0	-1.48	0	-1.48	0	-1.05	2	**FR**	-1.07	0	-1.07	0	-1.07	0	-1.07	0
GER	-1.37	1	-1.37	1	-1.37	1	-0.94	4	**GER**	-1.25	1	-1.25	1	-1.25	1	-1.08	2
GRE	-2.96**	0	-2.96**	0	-2.96**	0	-2.96**	0	**GRE**	-3.08**	0	-3.08**	0	-3.08**	0	-3.08**	0
IT	-3.41**	4	-3.06**	3	-3.06**	3	-2.89**	0	**IT**	-5.53***	1	-5.53***	1	-5.53***	1	-3.41**	0
JA	-0.5	4	-0.5	4	-0.5	4	-0.5	4	**JA**	-2.77*	3	-2.77*	3	-2.77*	3	-2.45	2
NETH	-2.17	2	-2.45	0	-2.45	0	-2.17	2	**NETH**	-2.37	0	-2.37	0	-2.37	0	-2.11	2
NZ	-4.78***	0	-4.78***	0	-4.78***	0	-4.78***	0	**NZ**	-1.41	0	-1.41	0	-1.41	0	-1.41	0
NOR	-2.24	3	-1.37	0	-1.37	0	-1.37	0	**NOR**	-4.67***	0	-4.67***	0	-4.67***	0	-4.67***	0
POR	-3.33**	4	-2.97**	3	-3.33**	4	-2.97**	3	**POR**	-3.96***	3	-3.29**	0	-3.29**	0	-3.29**	0
SP	-2.23	2	-2.23	2	-2.23	2	-2.23	2	**SP**	-5***	1	-5***	1	-5***	1	-4.08***	0
SWE	-1.88	1	-1.88	1	-1.88	1	-1.88	1	**SWE**	-5.93***	0	-5.93***	0	-5.93***	0	-5.93***	0
SWI	-3.48***	4	-3.77***	0	-3.77***	0	-3.01**	2	**SWI**	-6.82***	4	-6.59***	0	-6.59***	0	-6.59***	0
USA	-2.97**	2	-3.44**	0	-3.44**	0	-2.97**	2	**UK**	-0.39	4	-0.39	4	-0.39	4	-0.39	4
$\overline{CO}_{2t}$	-2.85*	0	-2.85*	0	-2.85*	0	-2.85*	0	**USA**	-3.38**	0	-3.38**	0	-3.38**	0	-2.58*	2
									$\overline{CO}_{2t}$	-4.8***	1	-4.25***	0	-4.8***	1	-4.25***	0
	9/21		**8/21**		**8/21**		**8/21**			**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.

Tab. 12: NON LINEAR KSS TEST 1950-2006

				1950				
COUNTRY	**AIC**	LAG	**BIC**	LAG	**HQ**	LAG	**MAIC**	LAG
AUS	-1.97	4	-2.65*	0	-2.65*	0	-1.63	3
AUSL	-3.06**	0	-3.06**	0	-3.06**	0	-2.78*	2
BEL	-1.91	2	-1.58	1	-1.91	2	-1.58	1
CA	-1.44	0	-1.44	0	-1.44	0	-1.44	0
DEN	-2.48*	0	-2.48*	0	-2.48*	0	-1.94	4
FIN	-4.27***	0	-4.27***	0	-4.27***	0	-3.72***	2
FR	-1.73	0	-1.73	0	-1.73	0	-1.47	1
GER	-2.89**	0	-2.89**	0	-2.89**	0	-2.27	1
GRE	1.71	0	1.71	0	1.71	0	1.71	0
IR	-0.12	4	-1.14	0	-1.2	1	-0.12	4
IT	-1.71	2	-1.71	2	-1.71	2	-0.15	1
JA	-3.59***	4	-3.59***	4	-3.59***	4	-2.19	0
NETH	-1.99	0	-1.99	0	-1.99	0	-1.99	0
NZ	-1.93	3	-2.11	0	-1.93	3	-1.79	1
NOR	-4.6***	0	-4.6***	0	-4.6***	0	-3.7***	1
POR	1.29	1	1.25	0	1.29	1	0.86	2
SP	0.35	0	0.35	0	0.35	0	0.35	0
SWE	-1.76	1	-1.98	0	-1.98	0	-1.76	1
SWI	-3.94***	4	-3.94***	4	-3.94***	4	-2.22	1
TUR	-0.07	0	-0.07	0	-0.07	0	-0.07	0
UK	-3.64***	0	-3.64***	0	-3.64***	0	-2.67*	1
USA	-2.2	4	-1.24	0	-2.2	4	-1.24	0
$\overline{CO}_{2t}$	-3.63***	2	-3.77***	1	-3.77***	1	-3.64***	0
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.

Tab. 13: CONVERGENCE VIA CARLINO AND MILLS' MEASURE

1870-2006									1950-2006								
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	AUS	-2.04	0	-2.04	0	-2.04	0	-1.77	1
AUSL	-4.91***	4	-5.07***	1	-4.91***	4	-4.1***	0	AUSL	-4.17***	0	-4.17***	0	-4.17***	0	-2.86**	2
BEL	-4.01***	3	-3.81***	1	-3.81***	1	-3.61***	0	BEL	-0.53	1	-0.53	1	-0.53	1	-0.53	1
CA	-3.37**	4	-2.46	0	-3.22**	3	-2.49	1	CA	-2.41	2	-2.41	2	-2.41	2	-2.07	0
DEN	-1.69	2	-1.98	0	-1.69	2	-1.69	2	DEN	-1.96	0	-1.96	0	-1.96	0	-0.77	4
FIN	-3.23**	0	-3.23**	0	-3.23**	0	-2.48	2	FIN	-2.4	4	-2.62*	0	-2.4	4	-2.62*	0
FR	-3.14**	3	-2.5	1	-2.5	1	-2.5	1	FR	-1.66	1	-1.66	1	-1.66	1	-1.66	1
GER	-5.14***	4	-5.17***	0	-5.14***	4	-4.79***	1	GER	-0.57	2	-0.57	2	-0.57	2	-0.57	2
GRE	-3.4**	0	-3.4**	0	-3.4**	0	-3.4**	0	GRE	1.41	4	0.79	0	1.08	1	0.79	0
IT	-5.41***	1	-5.41***	1	-5.41***	1	-3.8***	0	IR	-2.55*	1	-2.55*	1	-2.55*	1	-1.44	4
JA	-0.93	4	-0.93	4	-0.93	4	-0.93	4	IT	-2.21	0	-2.21	0	-2.21	0	-2.21	0
NETH	-1.64	4	-1.64	4	-1.64	4	-1.64	4	JA	-0.31	4	-0.75	0	-0.75	0	-0.31	4
NZ	-5.13***	4	-3.21**	0	-5.13***	4	-3.21**	0	NETH	-3.5***	0	-3.5***	0	-3.5***	0	-3.5***	0
NOR	-4.16***	4	-5.17***	0	-5.17***	0	-3.76***	3	NZ	-2.67*	2	-2.67*	2	-2.67*	2	-2.03	1
POR	-3.08**	3	-3.08**	3	-3.08**	3	-3.08**	3	NOR	-5.22***	2	-6.07***	0	-6.07***	0	-4.76***	1
SP	-5.69***	1	-5.69***	1	-5.69***	1	-4.89***	0	POR	0.52	1	0.52	1	0.52	1	0.3	3
SWE	-3.49***	1	-4.37***	0	-4.37***	0	-2.66*	3	SP	-1.43	2	-2.18	0	-1.43	2	-1.43	2
SWI	-6.81***	0	-6.81***	0	-6.81***	0	-6.81***	0	SWE	-3.53***	0	-3.53***	0	-3.53***	0	-2.62*	1
UK	-2.67*	0	-2.67*	0	-2.67*	0	-2.67*	0	SWI	-3.49***	4	-3.49***	4	-3.49***	4	-2.12	1
USA	-2.73*	0	-2.73*	0	-2.73*	0	-2.73*	0	TUR	-1.84	3	-2.5	0	-2.5	0	-1.79	2
TOTAL I(0)	17/20		15/20		16/20		13/20		UK	-0.41	4	1.61	0	1.61	0	-0.41	4
									USA	-1.6	4	-1.6	4	-1.6	4	-1.54	1
									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.

Tab. 14: CONVERGENCE VERSUS THE US

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	AUS	-0.15	4	-1.66	0	-1.66	0	-0.15	4
AUSL	-4.18***	2	-3.7***	1	-4.18***	2	-3.15**	0	AUSL	-2.7*	4	-3.89***	3	-3.89***	3	-2.73*	0
BEL	-4.25***	0	-4.25***	0	-4.25***	0	-4.25***	0	BEL	-4.69***	0	-4.69***	0	-4.69***	0	-3.25**	1
CA	-3.85***	4	-3.14**	3	-3.85***	4	-2.08	2	CA	-1.53	1	-2.31	0	-2.31	0	-1.36	2
DEN	-2.8*	3	-4.25***	0	-4.25***	0	-2.59*	2	DEN	-1.58	1	-1.59	0	-1.59	0	-0.8	4
FIN	-3.28**	0	-3.28**	0	-3.28**	0	-3.28**	0	FIN	-1.09	4	-1.65	3	-1.09	4	-1.09	4
FR	-3.38**	0	-3.38**	0	-3.38**	0	-3.38**	0	FR	-2.37	4	-2.94**	0	-2.94**	0	-2.3	1
GER	-6.1***	0	-6.1***	0	-6.1***	0	-3.9***	2	GER	-4.04***	0	-4.04***	0	-4.04***	0	-2	4
GRE	-2.99**	0	-2.99**	0	-2.99**	0	-2.99**	0	GRE	0.93	1	0.93	1	0.93	1	0.36	4
IT	-5.05***	1	-5.05***	1	-5.05***	1	-3.62***	0	IR	-1.39	3	-2.74*	0	-1.39	3	-1.39	3
JA	-2.47	4	-2.47	4	-2.47	4	-2.47	4	IT	-1.83	4	-2.87**	0	-2.87**	0	-2.22	1
NETH	-4.94***	0	-4.94***	0	-4.94***	0	-4.94***	0	JA	-1.05	0	-1.05	0	-1.05	0	-0.45	1
NZ	-2.55	0	-2.55	0	-2.55	0	-2.24	2	NETH	-1.11	0	-1.11	0	-1.11	0	-0.34	4
NOR	-3.96***	0	-3.96***	0	-3.96***	0	-3.96***	0	NZ	-2.1	4	-2.5	0	-2.2	2	-1.89	1
POR	-3.04**	3	-3.04**	3	-3.04**	3	-2.51	2	NOR	-0.99	1	-0.99	1	-0.99	1	-0.79	2
SP	-2.6*	2	-4.02***	0	-4.02***	0	-2.07	4	POR	0.71	1	0.71	1	0.71	1	0.56	0
SWE	-5.78***	0	-5.78***	0	-5.78***	0	-5.78***	0	SP	-0.75	2	-1.25	0	-0.75	2	-0.75	2
SWI	-5.22***	0	-5.22***	0	-5.22***	0	-5.22***	0	SWE	-3.39**	3	-3.39**	3	-3.39**	3	-2.61*	1
UK	-1.51	2	-1.51	2	-1.51	2	-1.51	2	SWI	-3.22**	4	-3.22**	4	-3.22**	4	-1.63	1
TOTAL I(0)	**16/19**		**16/19**		**16/19**		**13/19**		TUR	-1.37	0	-1.37	0	-1.37	0	0.05	3
									UK	-2.55*	4	-3.67***	0	-2.55*	4	-2.67*	2
									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.

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