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by

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Threshold cointegration and nonlinear adjustment between CO_2 and income: the environmental Kuznets curve in Spain, 1857-2007

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Abstract

In this paper we model the long-run relationship between per capita CO_2 and per capita income for the Spanish economy over the period 1857-2007. According to the Environmental Kuznets Curve (ECK) the relationship between the two variables has an inverted-U shape. However, previous studies for the Spanish economy only considered the existence of linear relationships. Such an approach may lack flexibility to detect the true shape of the relationship. Our empirical methodology accounts for a possible non-linear relationship through the use of threshold cointegration techniques. Our results confirm the non-linearity of the link between the two above-mentioned variables pointing to the existence of an Environmental Kuznets Curve for the Spanish case.

Keywords: Environmental Kuznets curve, CO_2 emissions, nonlinear relationship, threshold cointegration.

JEL classification: C2, Q4.

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1 Introduction

The Environmental Kuznets Curve (EKC) was first defined by Shafik and Bandyopadhyay (1992) and in Grossman and Krueger (1995). According to EKC hypothesis the relationship between income per capita and some types of pollution is approximately an inverted “U”. Initial studies were essentially empirical, and only recently, attention has been moving towards the theoretical aspects. At the first stage of economic development enviromental pressure increase as per capita income increases, but after a ”critical turning point” these pressures decrease along with higher per capita income levels. Empirically, evidence for the EKC hypothesis from CO_2 emissions is mixed (linear and nonlinear relationship).[1] Some papers find a linear relationship between per-capita CO_2 and per-capita GDP and others, somewhat more numerous, report an inverted -”U”- shaped relationship with estimated turning points and indicating a delinking of CO_2 emissions growth from economic growth.In the analysis of the emission-income relationship, there exists a set of theoretical models which derives inverted ”U” shaped curves by having emissions increasing with income until some threshold is passed, after which pollution is reduced.[2] The basic idea underlying all these model is that when some threshold income level is passed, then the economy moves to another regime, with the emission-income relationship being different between the old and the new regime. In the inverted ”U” models, the low income regime corresponds to an increasing emission-income relationship, while in the regime after the threshold the emission-income relationship is decreasing.

The explanatory mechanisms that the literature suggests, either individually or in combination, are basically the ones listed below and they conclude that the shape of the relationship is defined by the existence of a threshold.

First, from a theoretical point of view, the demand for environmental quality increases with income more than demand for other goods and services, leading to the existence of an income threshold below which there is no resource dedicated to environmental protection. However, when income rises, the population is both more able and more willing to sacrifice some of their consumption to protect the environment. Therefore, a high-income elasticity of environmental quality is a factor, which individually or with others, can generate a path of pollution decreasing over time. However, the willingness to pay for different categories of environmental goods is not

[1] For a literature review, see, for example, He and Richard (2010).
[2] For a literature review, see, for example, Levinson (2002).

uniform and, therefore, expected turning points may vary depending on the types of pollutants. For example, in the case of those contaminants that affect health directly will be achieved with lower rent. Secondly, another theoretical explanation would be that if the pollution is affecting production (for example, SO2 emissions that generate acid rain affect forests, agriculture and fishing) also the turning point will occur earlier. Third, the technology for reducing pollution is another factor that affects the curve (Andreoni and Levinson, 2001) depending on the existence of economies of scale. If there is economic growth, these economies of scale are more likely to occur. Fourthly, it is assumed that specialization and the growth that trade generates can facilitate the existence of the above-mentioned economies of scale, helping to reduce pollution in successive stages, as the technology spreads to other economies, giving rise to N-shaped curves instead of the classic inverted U. Finally, another factor that may explain the Kuznets curve are the structural changes inherent in the process of economic development, since the change of the productive structure (e.g., from primary industrial products to services and high technology-based products, which are less pollutants) also alters gradually the pollutant intensity.

There is an extensive empirical literature on the EKC, from the seminal work of Grossman and Krueger (1995) to the present, emphasizing the different aspects mentioned above of the relationship between emissions and per capita income (for a survey see Dinda (2004), Stern (2001) and more recently He and Richard (2010)). From a methodological point of view, the robustness of the results and the estimation of the turning points are sensitive to model specification (Harbaugh, Levinson and Wilson, 2002). The problem is that both income per capita and emissions are endogenous variables and they depend on their own determinants. As the theory predicts a long-run relationship linking emissions and economic growth, there is a wide stream of research that has assessed this relationship employing cointegration techniques. The empirical evidence suggests that economic development and GDP may be jointly determined, so that any constraint put on energy consumption to help reducing emissions will have effects on economic growth. Some authors, among others, Ozturk (2010), Halicioglu (2009), Chontanawatet al. (2008), Lise (2006), Lee (2005), Soytas and Sari (2003), Soytas et al. (2001), use cointegration procedures to examine CO2-GDP nexus, however the results are mixed with no clear consensus emerging. These studies have a common feature: the linear approach, which may be a possible cause of the heterogeneous findings obtained so far.

In order to account for the above-mentioned flaws, we analyze the nonlinear nature of the relationship between the variables and consider the possibility that the adjustment of the deviations towards the long-run equilibrium might not need to be symmetric, constant and reverting each period. The cost of adjustment or policy (discrete) interventions would invalidate de assumption of linearity. If nonlinearities are present, linear cointegration is capturing a global behaviour (i.e., an average behaviour across regimes), but locally, behaviour could be even nonstationary. The empirical approximation can be based on threshold models.

The basic idea underlying all these model is that when some threshold income level is passed, then the economy moves to another regime, with the emission-income relationship being different in the old and the new regime. In the inverted V models, the low-income regime corresponds to an increasing emission-income relationship, while in the regime after the threshold the emission-income relationship is decreasing. At the empirical level we estimate such a threshold time series model of the EKC associated with a threshold income level. Two main research issues in our study concern the possibility of the presence of a threshold in the long-run relationship and the asymmetric movements between per-capita CO2 and per-capita income.

In this paper we test for the presence of threshold cointegration between per-capita CO_2 and per-capita income for the Spanish economy during the period 1857 to 2007. The research analyzes two main issues: first, we study the possible presence of a threshold in the long-run relationship, and second, we estimate the asymmetric movements between per-capita CO_2 and per-capita income. As an extension to previous studies, we make use of the methodology developed by Hansen and Seo (2002), based on a threshold cointegration model. They propose an algorithm for estimating the complete threshold cointegration model and a $\sup LM$ test for the presence of a threshold. In particular, the threshold cointegration model allows for nonlinear adjustment to long-run equilibrium.

At the empirical level we estimate such a threshold time series model of the EKC associated with a threshold income level. The main contribution of our paper can be regarded as a confirmation of the EKC by using a different econometric approach.

The rest of the paper is organized as follows. Section 2 describes the empirical strategy employed in the analysis. Section 3 describes the data and reports the results. Section 4 concludes.

2 Threshold time series model of the environmental Kuznets curve

In order to test the EKC hypothesis from CO_2 emissions, the empirical studies commonly used a linear regression model such as:

$$CO_{2t} = \alpha + \beta y_t + \varepsilon_t \tag{1}$$

where CO_{2t} is per-capita CO_2 and y_t per-capita income. Alternatively, we may write the linear regression model (1) as a bivariate linear cointegrating VAR model with one lag, $l = 1$, such as:

$$\begin{pmatrix} \Delta CO_{2t} \\ \Delta y_t \end{pmatrix} = \mu + \alpha w_{t-1} + \Gamma \begin{pmatrix} \Delta CO_{2t-1} \\ \Delta y_{t-1} \end{pmatrix} + \varepsilon_t \tag{2}$$

where the long-run relationship is defined as $w_{t-1} = CO_{2t-1} - \beta y_{t-1}$.

Nevertheless, linearity, is not implied by the EKC hypothesis. In this paper, we explore the possibility that a threshold cointegration model provides a better empirical description.

The concept of threshold cointegration (or nonlinear cointegration) was first introduced by Balke and Fomby (1997) as a feasible way to combine nonlinearity and cointegration. Systems in which variables are cointegrated can be characterized by an error correction model (ECM), which describes how the variables respond to deviations from the equilibrium. Hence, the ECM can be characterized as the adjustment process along which the long-run equilibrium is maintained. However, the traditional approach, assumes that such a tendency to move towards the long-run equilibrium is present every time period.

Balke and Fomby (1997) stress the possibility that this movement towards the long-run equilibrium might not occur in every time period, due to the presence of some adjustment costs on the side of economic agents. In other words, there could be a discontinuous adjustment to equilibrium so that, only when the deviation from the equilibrium exceeds a critical threshold, the benefits of adjustment are higher than the costs, and economic agents move the system back to equilibrium. Threshold cointegration characterizes this discrete adjustment. This type of discrete adjustment could be particularly useful to describe the nonlinear behaviour of the EKC. Particularly, the model of threshold cointegration can be applied of EKC models which consider transaction costs and optimal adjustments [3] The ba-

[3] See, for example, Jaeger (1998), Joh and Pecchenino (1994), Jones and Manueli (2001), and Stockey (1998).

sic idea underlying all these models is that when some threshold income level is reached ("the income turning point"), with the emission-income relationship, the economy moves to another regime, with the emission-income relationship being different between the old and the new regime.

In a recent contribution, Hansen and Seo (2002) provide an important new refinement into the threshold cointegration methodology, by examining the case of an unknown cointegration vector. In particular, these authors propose a vector error-correction model (VECM) with one cointegrating vector and a threshold effect based on the error-correction term, and develop a Lagrange multiplier (LM) test for the presence of a threshold effect. This will be the approach followed in this paper.

Hansen and Seo (2002) consider a two-regime threshold cointegration model, or a nonlinear VECM of order $l+1$, such as:

$$\Delta x_t = \begin{cases} A_1' X_{t-1}(\beta) + u_t & \text{if } w_{t-1}(\beta) \leq \gamma \\ A_2' X_{t-1}(\beta) + u_t & \text{if } w_{t-1}(\beta) > \gamma \end{cases} \tag{3}$$

with

$$X_{t-1}(\beta) = \begin{pmatrix} 1 \\ w_{t-1}(\beta) \\ \Delta x_{t-1} \\ \Delta x_{t-2} \\ \vdots \\ \Delta x_{t-l} \end{pmatrix}$$

where x_t is a p-dimensional $I(1)$ time series which is cointegrated with one $p \times 1$ cointegrating vector β, $w_t(\beta) = \beta' x_t$ is the $I(0)$ error-correction term, u_t is an error term, A_1 and A_2 are coefficient matrices that describe the dynamics in each of the regimes, and γ is the threshold parameter.

As can be seen, the threshold model (3) has two regimes, defined by the value of the error-correction term. Model (3) allows all coefficients (except the cointegrating vector β) to switch between these two regimes.

Moreover, Hansen and Seo (2002) propose two heteroskedastic-consistent LM test statistics for the null hypothesis of linear cointegration (i.e., there is no threshold effect), against the alternative of threshold cointegration (i.e., model (3)). Under the null hypothesis there is no threshold, so the model reduces to a conventional linear VECM. The first test would be used when the true cointegrating vector is known a priori, and is denoted as:

$$\sup LM^0 = \sup_{\gamma_L \leq \gamma \leq \gamma_U} LM(\beta_0, \gamma) \tag{4}$$

where β_0 is the known value of β (i.e., $\beta_0 = 1$); whereas the second test would be used when the true cointegrating vector is unknown, and is denoted as:

$$\sup LM = \sup_{\gamma_L \leq \gamma \leq \gamma_U} LM(\tilde{\beta}, \gamma) \tag{5}$$

where $\tilde{\beta}$ is the null estimate of β. In both tests, $[\gamma_L, \gamma_U]$ is the search region set so that γ_L is the π_0 percentile of $\widetilde{w}_{t-1}$, and γ_U is the $(1 - \pi_0)$ percentile; Andrews (1993) suggests setting π_0 between 0.05 and 0.15. Finally, Hansen and Seo (2002) develop two bootstrap methods to calculate asymptotic critical values and p-values.

The aim of this study is to test for asymmetric transmission between per-capita CO_2 and per-capita income using the threshold cointegration. Unlike other methodologies that assume parameters are known *ex-ante,* the methodology of Hansen and Seo (2002) assumes both parameters β and γ are unknown and estimated from data ($\beta = \tilde{\beta}$).

3 Empirical Results

To carry out our analysis we employ time-series data on Spanish economy from 1857 to 2007: a) population: 1857-1990, from Carreras, A. and Tafunell, X. (2005), Table 2.5, and 1991-2007 from INE (2010), Table 2.1.8; b) real GDP: 1857-2000, from Carreras and Tafunell, X. (2005), Table 17.6, and 2001-2007, from Banco de España (2010), Table 1.3; c) total fossil fuel CO_2 (metric tonnes) from Boden, T.A et al, (2010). The evolution of the two series, per-capita CO_2, CO_{2t}, and per-capita income, y_t, is shown in Figure 1.

As a preliminary step in our analysis, we examine the time series properties of the series by testing for a unit root over the full sample. We have used a modified version of the Dickey-Fuller and Phillips-Perron tests proposed by Ng and Perron (2001), which try to solve the main problems present in these conventional tests for unit roots.

In general, the majority of the conventional unit root tests suffer from three problems. First, many tests have low power when the root of the autoregressive polynomial is close to, but less than, unit (Dejong *et al.,* 1992). Second, the majority of the tests suffer from severe size distortions when the moving-average polynomial of the first-differenced series has a large negative autoregressive root (Schwert, 1989; Perron and Ng, 1996). Third, the implementation of unit root tests often needs the selection of an autoregressive truncation lag, k; however, as discussed in Ng and Perron (1995) there is a strong association between k and the severity of size distortions and/or the extend of power loss.

Ng and Perron (2001) have proposed a methodology that solves these three problems. This method consists of a class of modified tests, called $\bar{M}^{GLS}_{MAIC}$, originally developed in Stock (1999) as M tests, with GLS detrending of the data as proposed in Elliot *et al.* (1996), and using the Modified Akaike Information Criteria ($MAIC$).[4] Also, Ng and Perron (2001) have proposed a similar procedure to correct for the problems of the standard Augmented Dickey-Fuller (ADF) test, ADF^{GLS}_{MAIC}.[5]

In Table 1 we report the results of the $\bar{M}^{GLS}_{MAIC}$ tests and the ADF^{GLS}_{MAIC} test. In all these tests the null hypothesis is that a series is I(1) against the alternative that it is I(0).[6] Our results clearly reject the existence of two unit roots for co_{2t} and y_t, at the usual significance levels. The null hypothesis of non-stationarity for the two series in levels can not be rejected in any of the tests applied. Consequently, we can conclude that both variables are I(1).

Here we apply the test of threshold cointegration proposed by Hansen and Seo (2002), namely, $\sup LM$ (estimated β) to our data. The $\sup LM$ statistic has a nonstandard asymptotic distribution as shown by Hansen and Seo (2002). They propose two bootstrapping techniques for calculating the p-values for $\sup LM$ test: one is the fixed regressor bootstrap and the other is the residual bootstrap (both are calculated with 5,000 simulation replications). We reject the null hypothesis of linear cointegration if the bootstrapping p-values are smaller than the size chosen.

Before we implement the test of threshold cointegration, we estimate the threshold VECM. To select the lag length of the VAR, we have used the AIC and BIC criteria, both of them leading to $l = 2$. The test statistics and p-values for model (3) are shown in Table 2.

Threshold cointegration would appear at the 2% significance level for the $\sup LM$ test, with β estimated at 0.88. The implication of this estimated long-run coefficient is that the effect of income on emissions is positive and smaller than 1.[7]

[4] These tests are the $\bar{M}Z^{GLS}_{\alpha}$, $\bar{M}SB^{GLS}$ and $\bar{M}Z^{GLS}_{t}$.

[5] See Ng and Perron (2001) and Perron and Ng (1996) for a detailed description of these tests.

[6] Note that for the $\bar{M}SB^{GLS}$ test, the null hypothesis is rejected in favour of stationarity when the estimated value is smaller than the critical value.

[7] The evidence of bivariate threshold cointegration using both bootstrapping techniques clearly rejects the null hypothesis of linear cointegration. Consequently, the threshold cointegration model of the environmental Kuznets curve is more suitable for our data. Our results contrast with the empiral evidence presented by Roca et al. (2001). They investigate the EKC hypothesis with CO_2 emissions data from Spain from 1973-1996 and

The results yield a threshold at a per capita income of $\hat{\gamma} = 8266$ euros, which divides the sample into two regimes. The first or unusual regime with per-capita income ≥ 8266 euros (with 15% of the observations): 1986-2007. In turn, the second or typical regime with per-capita income < 8266 euros (with 85% of the observations): 1857-1985.

The corresponding two-regime threshold VAR (with heteroskedasticity-consistent standard errors in parentheses) is given below:

$$\Delta CO_{2t} = \begin{cases} \underset{(0.97)}{-3.31} - \underset{(0.10)}{0.36}\ w_{t-1} - \underset{(0.23)}{0.14}\ \Delta CO_{2t-1} \underset{(0.21)}{-0.03}\ \Delta CO_{2t-2} \\ \quad - \underset{(0.11)}{0.42}\ \Delta y_{t-1} - \underset{(0.18)}{0.81}\ \Delta y_{t-2} + u_{1t},\ w_{t-1} \geqslant 8266 \\ \\ \underset{(0.13)}{-0.16} - \underset{(0.01)}{0.02}\ w_{t-1} + \underset{(0.08)}{0.15}\ \Delta CO_{2t-1} + \underset{(0.19)}{0.69}\ \Delta CO_{2t-2} \\ \quad + \underset{(0.10)}{0.10}\ \Delta y_{t-1} + \underset{(0.19)}{0.04}\ \Delta y_{t-2} + u_{2t},\ w_{t-1} < 8266 \end{cases} \tag{6}$$

$$\Delta y_t = \begin{cases} \underset{(0.46)}{1.35} + \underset{(0.05)}{0.14}\ w_{t-1} + \underset{(0.15)}{0.12}\ \Delta CO_{2t-1} + \underset{(0.20)}{0.09}\ \Delta CO_{2t-2} \\ \quad + \underset{(0.09)}{0.04}\ \Delta y_{t-1} - \underset{(0.20)}{0.33}\ \Delta y_{t-2} + u_{1t},\ w_{t-1} \geqslant 8266 \\ \\ \underset{(0.05)}{0.23} + \underset{(0.007)}{0.02}\ w_{t-1} + \underset{(0.03)}{0.03}\ \Delta CO_{2t-1} + \underset{(0.08)}{0.15}\ \Delta CO_{2t-2} \\ \quad + \underset{(0.03)}{0.02}\ \Delta y_{t-1} + \underset{(0.08)}{0.01}\ \Delta y_{t-2} + u_{2t},\ w_{t-1} < 8266 \end{cases} \tag{7}$$

The estimation of the error-correction term in the VAR lag-length 4, w_{t-1}, allows for a straightforward investigation into the behavior of the long-run relationship and the asymmetric movements between per-capita CO_2 and per-capita income in Spanish economy. We can also examine the sign and magnitude of these coefficients in order to analyze the adjustment process by which long-run equilibrium between both series is restored. First, there is a strong and statistically significant error-correction term in the first regime, i.e., when per-capita income ≥ 8266 euros. On the contrary, in the second regime, i.e., when per-capita income < 8266 euros, error-correction effects are minimal in terms of size of the coefficients.

Figure 2 shows the response function of per-capita CO_2 and per-capita income to the discrepancy between the former and the adjustment for the latter, in the previous period. The response function is based on the estimates of the intercept and the adjustment vector in each regime given the

find that long-run elasticity between income and CO_2 emissions is positive and greater than 1 ($\beta = 1.24$), revealing a very strong linear cointegration between these two variables.

other short-run dynamics. It can be seen the flat, near zero, error-correction effect on the right-hand side of the threshold parameter (when per-capita income < 8266 euros) for both per-capita CO_2 and per-capita income. This implies that the divergence between per-capita CO_2 and per-capita income is persistent because both variables do not respond to the error-correction term. Moreover, on the left-hand side of the threshold parameter (when per-capita income ≥ 8266 euros) the response of per-capita CO_2 and per-capita income to error correction is significant. There is a sharp negative relationship for per-capita CO_2 (per-capita CO_2 decreases as the error-correction term increases) and a sharp positive relationship for per-capita income (per capita income increases as the error-correction term increases).

4 Conclusions

This article re-addresses the pollution-income path of EKC, but from a different perspective. We test for the presence of threshold cointegration between per-capita CO_2 and per-capita income for the Spanish economy during the period 1857 to 2007. Two main research issues in this study concern the possibility of the presence of a threshold in the long-run relationship and the asymmetric movements between per-capita CO_2 and per-capita income. As an extension of previous studies, we make use of the methodology developed by Hansen and Seo (2002), based on a threshold cointegration model. This approach proposes an algorithm for estimating the complete threshold cointegration model and a $\sup LM$ test for the presence of a threshold. In particular, the threshold cointegration model allows for nonlinear adjustment to long-run equilibrium. This type of discrete adjustment could be particularly useful to describe the nonlinear behaviour of the EKC. Particularly, the model of threshold cointegration can be applied of EKC models which consider transaction costs and optimal adjustments. [8] The basic idea underlying all these models is that when some threshold income level is reached ("the income turning point"), with the emission-income relationship, the economy moves to another regime, with the emission-income relationship being different between the old and the new regime.

According to our results, the null hypothesis of linear cointegration would be rejected in favor of a two-regime threshold cointegration model. Consequently, a system of two regimes would seem to characterize the discontinuous or nonlinear adjustment of per-capita CO_2 towards a long-run equilib-

[8] See, for example, Jaeger (1998), Joh and Pecchenino (1994), Jones and Manueli (2001), and Stockey (1998).

rium relationship. The results yield a threshold at a per capita income of $\hat{\gamma} = 8266$ euros, which divides the sample into two regimes. The unusual regime with per-capita income ≥ 8266 euros (with 15% of the observations): 1986-2007. In turn, the typical regime with per-capita income < 8266 euros (with 85% of the observations): 1857-1985. In the typical regime, the response of per-capita CO_2 and per-capita income to error correction is minimal, which implies that the divergence between per-capita CO_2 and per-capita income is persistent. On the contrary, in the unusual regime, the response of per-capita CO_2 and per-capita income to error correction is significant. Now, there is a sharp negative relationship for per-capita CO_2 (per-capita CO_2 decreases as the error-correction term increases) and a sharp positive relationship for per-capita income (per capita income increases as the error-correction term increases). Our results confirm and complement the empirical literature regarding inverted "U" shaped curves for CO_2 emissions.

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Table 1
Ng-Perron tests for a unit roots

I(2) vs. I(1)	Case: $p = 0, \bar{c} = -7.0$			
Variable	$\bar{M}Z_{\alpha}^{GLS}$	$\bar{M}Z_{t}^{GLS}$	$\bar{M}SB^{GLS}$	ADF^{GLS}
ΔCO_{2t}	-48.95***	-4.94***	0.101	-6.36***
Δy_t	-23.62***	-3.36***	0.142	-3.57***
I(1) vs. I(0)	Case: $p = 1, \bar{c} = -13.5$			
Variable	$\bar{M}Z_{\alpha}^{GLS}$	$\bar{M}Z_{t}^{GLS}$	$\bar{M}SB^{GLS}$	ADF^{GLS}
CO_{2t}	0.23	0.13	0.599***	0.11
y_t	0.83	0.44	0.537***	0.63

Notes:
[a] A *, ** and *** denote significance at the 10%, 5% and 1% levels, respectively.
[b] The $MAIC$ information criteria is used to select the autoregressive truncation lag, k, as proposed in Perron and Ng (1996). The critical values are taken from Ng and Perron (2001), table 1:

Critical values:	Case: $p = 0, \bar{c} = -7.0$			Case: $p = 1, \bar{c} = -13.5$		
	10%	5%	1%	10%	5%	1%
$\bar{M}Z_{\alpha}^{GLS}$	-5.7	-8.1	-13.8	-14.2	-17.3	-23.8
$\bar{M}SB^{GLS}$	0.275	0.233	0.174	0.185	0.168	0.143
$\bar{M}Z_{t}^{GLS}, ADF^{GLS}$	-1.62	-1.98	-2.58	-2.62	-2.91	-3.42

Table 2
Tests for threshold cointegration

	$\sup LM$
Estimates	$l = 2$
Cointegrating vector β	0.88
Threshold parameter γ	9.02
(antilog)	8266 euros
$\sup LM$ test value	23.81
Residual Bootstrap C.V.	21.77
(p-value)	(0.022)

Figure 1. Evolution of per-capita income and per-capita CO_2

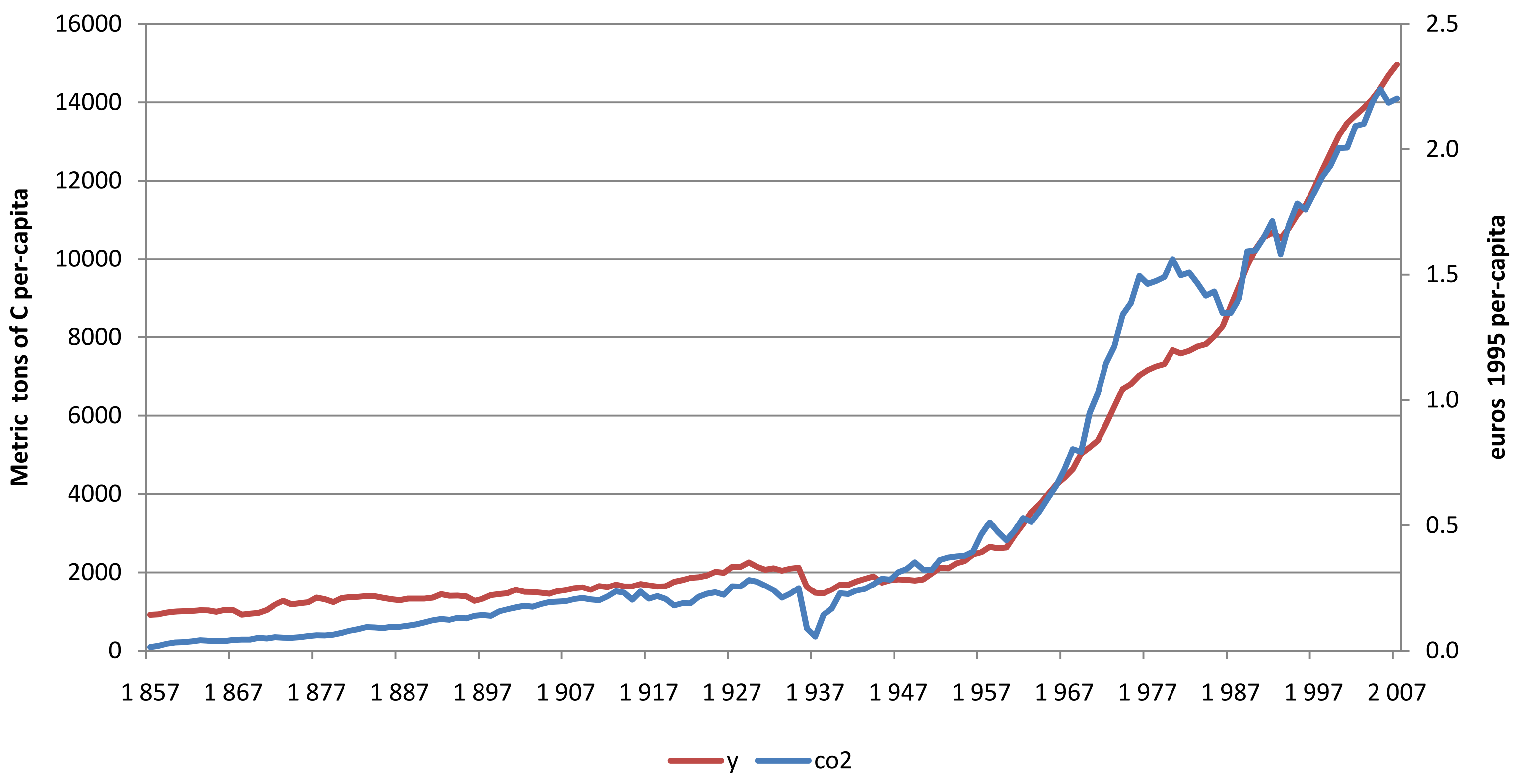

Figure 2

Response of income and CO2 to error correction, 1857–2007