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Air Emissions Performance: A Dynamic Analysis for Spain

JUAN A. ROMÁN-ASO
CESTE, International Business School
JAIME VALLÉS-GIMÉNEZ
University of Zaragoza

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Abstract

This paper investigates the dynamic performance of air pollution in Spain from 1960 to 2010. First, we evaluate the relationship between economic growth and pollution through the Environmental Kuznets Curve. Second, we test the hypothesis of regional convergence in air pollution intensity from 1995 to 2010, in order to analyse whether regional taxes intended to abate emissions have been effective. For the first issue, our results show that a quadratic relationship is satisfied, but an out-of-sample turning point is generated. For the second, regional convergence is rejected, although those regions which have implemented a pollution tax seem to perform differently.

Keywords: Dynamic performance, Air pollution tax.

JEL Classification: N50, O13, Q20.

1. Introduction

The dynamic behaviour of air pollution has been broadly investigated in the last decades, in particular the relationship between economic growth and environmental deterioration in the long term. Within this scope, the most common theory clearly differentiates between two phases. At first, economic growth leads to an increase in pollution, since the early stage of development is usually associated with transfers of capital and labour from agriculture to industry. Once this development is consolidated, the role of industry begins to decline in favour of less polluting sectors. From this turning point, the economy starts to import pollution-intensive goods, which were formerly produced. Thus, pollution growth seems to be a temporary consequence of economic development and public intervention should be unnecessary.

Its origin lies in the contribution of Kuznets (1955), who asserted that when a country is in the first stage of development, inequality increases until a turning point is reached. This process described an inverted U-shaped curve, called the Kuznets Curve. In the early 90s, Grossman and Krueger (1991, 1994) and Shafik and Bandyopadhyay (1992), among others, transferred the Kuznets Curve to the field of natural resources, obtaining empirical evidence that some pollutants display the properties of an inverted U-shaped curve. On the strength of these results, the World Bank supported this hypothesis, and finally, Panayotou (1993) coined the term Environmental Kuznets Curve (hereafter EKC).

Grossman and Krueger (1991) and more recently Stern (2004) determined that the relationship between air pollution and economic growth is based on three main effects. In the first, known as the scale effect, increased pollution is a consequence of production growth in the first stage. Movement in the opposite direction, with factors of production moving from secondary industry to the tertiary sector after the turning point, leads to lower emissions: this is the output substitution effect. Finally, the above authors also consider the potential decrease in pollution derived from changes in productivity and competitiveness through the implementation of RandD activities. This is called the technology effect.

In this paper, we will test the existence of the Environmental Kuznets Curve for the Spanish economy in the period 1960-2010. After analysing its dynamic evolution, we will focus on the stochastic convergence of pollution intensity from 1995 to 2010 across the country, in order to investigate whether the implementation of environmental tax policies (for which regional governments are responsible) has encouraged pollution abatement. If this hypothesis is satisfied, we can conclude that regional tax policy is an important element for homogenizing the intensity of pollution among regions [1]. Stochastic convergence is based on the hypothesis that a random magnitude evolves according to a pattern and tends to become harmonised over time. The seminal contribution was developed by Solow (1956) for per capita income across countries, and the technique has recently moved into the area of environmental research.

The rest of the paper is organized as follows: section 2 reviews empirical literature for the EKC, section 3 describes the sample and the econometric method, sections 4 and 5 show our empirical results, including the analysis of the stochastic convergence described above, and finally section 6 concludes with analytical results and graphs and suggests some political implications.

2. Literature review

The empirical existence of the EKC has led to a great number of academic works in recent decades. An excellent literature review is presented in the work of Cavlovic *et al.* (2000). The authors find that studies 'that estimate the empirical income-environment relationship for developed countries tend to find lower income turning points' (Cavlovic *et al.*, 2000: 38) and they also confirm that the studies that include trade effects as explanatory variables obtain higher income turning points. Therefore, they conclude that assessing methodological choices affects the empirical results. The role of the sample selected in the EKC test is also analysed in the meta-analysis of Stern (2004), which points out that developing countries are implementing new environmental policies designed to internalize the effects of pollution more effectively than developed countries, and in consequence, the classic concept of EKC is no longer realistic.

From a similar point of view, Dinda (2004) reviews the possible explanations for the existence of the EKC, and the main findings obtained in the literature. The author excludes the possibility of a global EKC, based on previous works. He asserts that '…only some air quality indicators, especially local pollutants, show the evidence of an EKC. However, an EKC is empirically observed' (Dinda, 2004: 431). The empirical existence of the EKC for all pollutants had been rejected in all periods, as we can see in Dinda *et al.* (2000) and Stern and Common (2001), respectively. Nevertheless, in the last decade, many academic works have attempted to solve this hypothesis from different perspectives and with many different results, as described below.

For a small developed economy, like Austria, Friedl and Getzner (2003) present a model that relates carbon dioxide emissions to income, and also to climatic, structural and time-specific variables from 1960 to 1999. Their results conclude that environmental policies are still needed to stimulate emissions abatement, since economic growth alone is not a guarantee of better environmental performance. However, Aviral-Kumar and Shahbaz's 2013 paper on the economy of India, considered one of the most important developing countries around the world, does not reject the hypothesis of the EKC in the long term.

Azomahou *et al.* (2006) use a panel dataset of 100 countries and propose the use of a nonparametric test for poolability, which proves the structural stability of the relationship between economic growth and pollution. They also specify a panel data model that enables them to confirm that this relationship is upward sloping and consequently, they question the existence of the EKC.

In contrast, we find Hong and Wagner (2008: 6) where a 'fully modified OLS estimation, specification tests based on augmented and auxiliary regressions, as well as a sub-sample KPSS type cointegration test' are provided. This refers to the test developed by Kwiatkowski *et al.* (1992). Their results demonstrated the existence of the EKC in roughly half of the 19 early industrialised countries over the period 1870-2000, for carbon dioxide and sulphur emissions. More recently, Iwata *et al.* (2010) specified a model that analyses the EKC for 11 OECD countries, by paying particular attention to the role of nuclear energy in emissions abatement. Their finding satisfies the hypothesis in Finland, Japan, Korea and Spain, but the turning point is outside the sample period in most cases.

Finally, since our purpose is to examine the Spanish case, we highlight one of the seminal contributions to the EKC, by Roca *et al.* (2001). Their results show that there is no evidence for the hypothesis, except for sulphur dioxide. In addition, the authors conclude that the 'relationship between income level and different types of emissions depends on many factors' (Roca *et al.* 2001: 85) and consequently economic growth alone cannot reduce emissions.

In contrast, the work of Cantos and Balsalobre (2011) proves the existence of the EKC through an econometric model which evaluates the impact of income (quadratic), the Gini index, and the quotient between consumption of renewable energy and consumption for traditional sources on pollution per capita.

As cited above, the results of an econometric regression can be strongly sensitive to the sample, and for that reason, Esteve and Tamarit (2012a) suggested a methodology based on a linear cointegrated regression model, over the period 1857-2007. As a result, they found that the coefficient between per capita carbon dioxide emissions and per capita income tends to decrease during that period. Then the hypothesis of EKC is not accepted, but empirical evidence showed that per capita carbon dioxide consumption follows 'a decreasing growth path pointing to a prospective turning point' (Esteve and Tamarit, 2012a: 2696). Once again, Esteve and Tamarit (2012b) tested for the EKC, through the application of a threshold cointegration analysis (based on a stationary relationship in the long term and a countervail mechanism in case of shock), and they confirmed its existence[2].

Recently, Iglesias *et al.* (2013) proposed the methodology of Kejriwal-Perron (2010), to tests for multiple structural breaks in cointegrated regression models, by using a dataset from 1850 to 2008. They concluded that the relationship between economic growth and carbon dioxide emissions differs over time, but found no evidence of the EKC. However, the authors pointed out that the recent change in that relationship could satisfy the EKC in the future. From the work of Esteve and Tamarit (2012b), Sephton and Mann (2013) prove there is a non-linear cointegration and asymmetric adjustment between per capita income and CO_2 levels.

In summary, most of the research reviewed rejects the existence of the EKC for all assumptions. Actually, it usually argues that the relationship between CO_2 and GDP varies depending on period, hence there is no strong evidence to support this hypothesis, although it can be satisfied under certain assumptions. For the Spanish case, the hypothesis has been investigated by employing a large dataset (more than 100 years). However, Spain did not experience significant economic growth until the 1960s. For that reason, we propose testing the existence of the EKC over the period 1960-2010, by applying the cointegration method and regression model.

3. Data and methodology

Carbon dioxide emissions per capita and real income per capita are the variables of interest in this paper. They are denoted by CO_2/cap_t and GDP/cap_t respectively, where subscript 't' indicates the year. Both variables are transformed by taking their natural logarithms in order to control for heteroscedasticity, and additionally, we want to obtain elasticity that will allow us to capture other kinds of relationship other than linear.

Carbon dioxide is measured in millions of metric tons, with data from the Carbon Dioxide Information Analysis Center (CDIAC) of Oak Ridge National Laboratory in the US. According to Doda (2013: 4), CDIAC is one of the 'most reliable, comprehensive and current databases with long time series for carbon dioxide emissions for all countries of the world'. On the other hand, the historical datasets of income are collected in the following books: Monitoring the World Economy 1820-1992, OECD, (1995); The World Economy: A Millennial Perspective, OECD Development Centre, (2001) and The World Economy: Historical Statistics, OECD Development Centre, (2010). Finally, population data are gathered from the database of the Groningen Growth and Development Centre.

Figure 1 represents the evolution of carbon dioxide emissions and income, from the early 1960s to 2010. Figure 1 shows that emissions per capita significantly increase up to 20,000 €. From that point, they start to decline and seem to show an inverted U shape. However, carbon dioxide performance is difficult to predict in the long term. For that reason, we expect that our empirical model will help to clarify the issue.

Figure 1. Carbon dioxide emissions and income from 1960 to 2010 in Spain*.

Source: by the authors, based on CDIAC and OCDE data. (*): Units of carbon dioxide and Gross Domestic Product per capita in €.

The EKC hypothesis, which states that any country after exceeding a concrete level of GDP per capita, called the turning point, begins to reduce pollution per capita, holds in this case. This requires the existence of a stable relationship between both variables, which should be stationary around a trend. In order to demonstrate this hypothesis, we suggest testing cointegration for emissions and income. The method is based on the error correction model of Engle-Granger (1987), which examines the short-term and the long-term relationship through residual analysis of the regression between both variables.

The first step of the Engle-Granger method is to investigate whether both series are integrated of the same order. According to Maddala and Kim (1998), employing several tests to analyse the stationarity of economic series is frequent in the empirical literature. The most common are those proposed by Ng and Perron (2001) and KPSS (Kwiatkowski *et al.*, 1992). The former refers to the modified Dickey Fuller Test, with the optimal number of lags determined by the AIC criteria. The latter is a stationarity test and according to DeJong *et al.* (1992a), it has more power than unit root tests. The optimal number of lags is suggested by Newey and West (1994).

In both tests, we include a deterministic trend in order to capture its evolution over time adequately. The use of a trend was seminally proposed by Dickey and Fuller (1979) based on the previous research on the velocity of money by Gould and Nelson (1974). Following Dickey and Fuller (1981) and Elliot, Rothenberg, and Stock (1996), we suggest the use of the following equation:

$$\Delta y_t \quad \alpha + \delta t + \rho y_{t-1} + \beta \sum_{i\ 1}^{k} \Delta y_{t-i} + \varepsilon_t \tag{1}$$

The results can be reviewed in table 1.

Table 1
NG-PERRON AND KPSS TESTS

Variable	Ng-Perron (Optimal Lag)	Ho: non-stationarity Conclusion at 5%	KPSS (Optimal Lag)	Ho: trend-stationarity Conclusion at 5%
$\ln(CO_2/cap)$	-0.876 (2)	Not Rejected	0.349 (2)	Rejected
ln(GDP/cap)	-1.433 (2)	Not Rejected	0.245 (2)	Rejected
$d[\ln(CO_2/cap)]$	-1.906 (2)	Not Rejected	0.116 (2)	Not Rejected
d[ln(GDP/cap)]	-2.113 (1)	Not Rejected	0.145 (5)	Not Rejected
$d^2[\ln(CO_2/cap)]$	-6.801 (1)	Rejected		
$d^2[\ln(GDP/cap)]$	-4.230 (1)	Rejected		

With regards to the previous literature (Esteve and Tamarit, 2012b or Iglesias, 2013, among others) it is difficult to assume the Ng-Perron test outcome of table 1. Being integrated of order 2 could imply that the relationship has a concave shape and that does not fit with the nature of economic growth. However, the medium and long term pollution performance and the fact that our sample size is not large enough bring our main result even more into question[3].

According to some empirical examples reviewed in Section 2 (Hong and Wagner, 2008; Esteve and Tamarit, 2012b; or Sephton and Mann, 2013, among others) and the KPSS test outcome, we conclude that pollution and income series are integrated of order 1. To detect their evolution, we use the deterministic trend as recommended in Dickey and Fuller (1979, 1981).

After determining that both are integrated of the same order, a significant amount of work lies ahead of us. First, we need to check whether they are related, and if there actually is a stable relationship between them. For this purpose, we suggest the following regression:

$$\ln(CO_2/cap)_t \quad \beta_0 + \beta_1 \ln(GDP/cap)_t + \beta_2 t + \varepsilon_t \tag{2}$$

Where t represents a deterministic trend, included to capture the evolution of the dependent variable over time and $\hat{\varepsilon}_t$ is the error term that reflects the effect of a disturbance in the equilibrium between pollution and income. Following this estimation, we suggest an error correction model that covers the short-term and long-term effects derived from a shock in the independent variable.

$$d\ln(CO_2/cap)_t \quad \beta_0 + \beta_1 d[\ln(GDP/cap)]_{t-1} + \beta_2 \hat{\varepsilon}_{t-1} + u_t \tag{3}$$

Where $\hat{\varepsilon}_{t-1}$ is the lagged residual of equation (2) and the coefficient β_2 refers to the error correcting mechanism in the long term[4]. It is expected to be a negative sign, since its role is to countervail the effect. On the other hand, the coefficient β_1 determines the short-term effect of a change in per capita income growth rate on the dependent variable. Thus, it measures the strength of the relation between both variables, and consequently, it is also expected to be negative.

Additionally, we must evaluate whether this relationship can be considered as an EKC. Attending to the study of the Portuguese economy by Shahbaz *et al.* (2010), we propose the Granger causality Wald tests that will let us identify the directionality of the effects.

Meanwhile, to test for the existence of a quadratic relationship we include the square of per capita income in equation (2), such that:

$$\ln(CO_2/cap)_t \quad \beta_0 + \beta_1 \ln(GDP/cap)_t + \beta_2 [\ln(GDP/cap)]_t^2 + \beta_3 t + u_t \tag{4}$$

We also examine the evolution of the linkage between pollution and income over the entire period, as well. In our database, it is possible to disentangle three different phases in the evolution of economic growth (figure 2). First, the period from 1960 to 1980 is clearly characterized as a phase of economic expansion and at the same time, pollution growth oscillates around 5%. In the second period (1981-1993), economic growth tends to be lower and pollution ranges from negative to positive. Finally, we can observe an increase in the annual growth rates from 1994 to 2008, while pollution decreases at the end of this phase.

The literature frequently refers to the problems of EKC specification, in particular the omission of relevant variables, (Stern and Common, 2001 or Díaz-Vázquez, 2009, among others). However, this technique is still the most common in cointegration analysis.

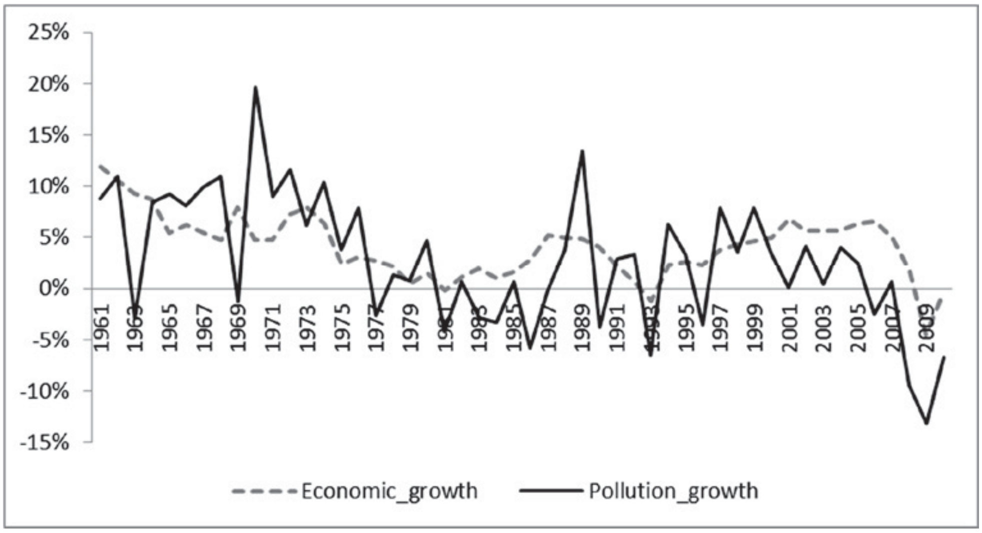

Figure 2. Annual growth rates of income and pollution from 1960 to 2010 in Spain

Source: by the authors, based on CDIAC and OCDE data.

Thus, our sample is divided into three subsamples to detect the impact of different socioeconomic features on this relationship, as suggested by Dinda *et al.* (2000) and Frield and Getzner (2003). These phases are denoted by d_1, d_2 and d_3.

- d_1:1960-1980; industrialisation.
- d_2:1981-1993; economic growth and industrial restructuring.
- d_3:1994-2010; final phase of economic growth. Regional governments implement taxes on emissions. The impact of these taxes is evaluated in section 5.

To conclude, we will implement the Engle –Granger Test for equation (4) in order to conclude whether or not the EKC relationship is stable.

4. Empirical results

Table 2 presents the empirical results of the application of Engle-Granger methodology to our dataset. The OLS estimates for model (2) reflect that carbon dioxide emissions per capita and income are positively related, and therefore, economic growth generates an increase in pollution, as described in the scale effect (Section 1) and also frequently supported in earlier literature for Spain (Cantos and Balsalobre, 2011, Esteve and Tamarit, 2012b and Iglesias *et al.* 2013). Our sample gathers data from 1960 to 2010. The beginning of the economic crisis in 2008 leads us to question if excluding data from 2008-2010 can change the empirical results. For that reason, we have also provided results from 1960-2008, which are presented in the left column.

Table 2
ENGLE-GRANGER

Variable	1960-2008	1960-2010
Engle-Granger 1st-step: Regression		
ln(GDP/cap)	1.590338	1.601719
	(10.49)***	(8.12) ***
Trend	-0.0268201	-0.0299775
	(-4.94) ***	(-4.26) ***
Intercept	-12.38316	-12.43387
	(-9.80) ***	(-7.56) ***
Engle-Granger 2-step: Error Correction Model		
$\hat{\varepsilon}_{t-1}$	-0.0336871	0.0275618
	(-0.36)	(0.41)
$d[\ln(GDP/cap)]_{t-1}$	0.7501304	1.000127
	(2.07)**	(3.42) ***
Intercept	-0.0021731	-0.0163064
	(-0.12)	(-1.12)

[a] *Note:* *Significance at 10%. ** Significance at 5%. *** Significance at 1%.

With respect to stationarity, our finding shows that the correcting effect in the long term represented by ε_{t-1} is not significant. However, the first order difference of lagged income is significant at 1%. Thus, there is evidence that deviations from equilibrium are not corrected in the long term, or at least, not as fast as in the short term. This finding underlines that linkage is not stationary, and the hypothesis of EKC must be rejected in accordance with the empirical result. However, the sample employed in this investigation is not as large as required to obtain consistent results in the long term, and the coefficient may be influenced by this. Therefore we test for the causal relationship between per capita income squared with carbon dioxide emissions per capita in table 3. Results vary little depending on sample restriction.

Table 3
GRANGER CAUSALITY WALD TESTS

1960-2008	Coefficient chi2	p-value
ln(GDP/cap) does not impact on ln(CO_2/cap)	9.8676	0.007
[ln(GDP/cap)]^2 does not impact on a ln(CO_2/cap)	9.7444	0.008
ln(CO_2/cap) does not impact on ln(GDP/cap)	1.9445	0.378
ln(CO_2/cap) does not impact on ln[(GDP/cap)]^2	1.6585	0.436
1960-2010	**Coefficient chi2**	**p-value**
ln(GDP/cap) does not impact on ln(CO_2/cap)	16.869	0.000
[ln(GDP/cap)]^2 does not impact on a ln(CO_2/cap)	15.556	0.000
ln(CO_2/cap) does not impact on ln(GDP/cap)	0.15337	0.926
ln(CO_2/cap) does not impact on [ln(GDP/cap)]^2	0.26706	0.875

The Granger causality Wald test results determine that carbon dioxide emissions per capita are significantly influenced by per capita income squared (15.556). This should confirm the existence of a non-linear relationship between both variables and, consequently, the EKC hypothesis is satisfied for the period 1960-2010. It contradicts the result of cointegration, which rejected the effect in the long term, and obviously, stationarity. With respect to the shorter period sample, the test outcome reveals that there are no significant changes.

This outcome will again be analysed with the estimation of model (4). If the EKC takes place, per capita income squared should affect carbon dioxide emissions per capita, in order to capture the potential nonlinear relationship. For that purpose, we suggest the Cochrane–Orcutt methodology with robust standard errors. With respect to the income turning point, we employ the following expression $\exp(-\beta_1/2\beta_2)$, which is widely accepted in the literature. As expected, we find a positive impact of income per capita on carbon dioxide emissions, and we also prove the significance of per capita income squared. This could be evidence of the EKC as previously observed in the Granger causality Wald tests and according to Cantos and Balsalobre (2011), and Esteve and Tamarit (2012b).

However, the value of the turning point (40,036.22 €) is outside the sample (the same problem as in Iwata *et al.*, 2010), which shows that the findings of this model are inconclusive, and the evidence for the EKC is strongly questioned. The right-hand column shows the restricted sample results for equation (4). The estimators are very similar to that obtained for the entire sample, and the turning point is slightly above 42,530 €.

The second row of table 4 determines how strong the relationship is between per capita income and pollution for every sub-sample. As we can observe, the significance of the coefficient β_1 started to decline in the second period, i.e. from the mid-1990s up to 2010, and this relationship is not significant. This evidence is consistent with the non-stationarity obtained in the application of the Engle-Granger methodology.

Lastly, the stability of EKC, determined by the relationship between variables in equation (4) is tested through Engle- Granger. Results determine that linkage is stable in the long term for both the entire sample and the restricted sample. The results are shown in table 4:

Table 4
COCHRANE-ORCUTT ESTIMATION RESULTS

Variable	d_1:1960-1980 Coefficient	d_2:1981-1993 Coefficient	d_3:1994-2010 Coefficient	1960-2010 Coefficient	1996-2008 Coefficient
Intercept	-10.88308 (-15.34)***	-1.966959 (-1.03)	0.7994824 (0.41)	-56.06309 (-6.61)***	-46.30788 (-6.45)***
ln(GDP/cap)	1.383469 (17.42)***	0.3924469 (1.91)*	0.1166928 (0.59)	11.20565 (6.45)***	9.177057 (6.22)***
$[\ln(GDP/cap)]^2$	-	-	-	-0.5286911 (-5.98)***	-0.4251485 (-5.62)***
Trend	-	-	-	-0.0238258 (-3.21)**	-0.0183871 (-2.93)**
R^2	0.9589	0.2779	0.0220	0.8935	0.9302
F-statistic (p-value)	-	-	-	F(3,46) = 74.65 Prob'F= 0.0000	F(3,43)= 142.82 Prob'F= 0.0000
Income turning point	**-**	**-**	**-**	**40,036.22 €**	**42,531.91 €**
Stability of EKC					
Significance Test of in Error Correction model for equation (3)				-0.2169804 (-2.13)***	-0.2650558 (-2.61)**

Variable	d_1:1960-1980 Coefficient	d_2:1981-1993 Coefficient	d_3:1994-2010 Coefficient	1960-2010 Coefficient	1996-2008 Coefficient
$[d[\ln(GDP/cap)]]_{t-1}$				2.732575 (1.20)	4.686243 $(2.28)^{**}$
$[d[\ln(GDP/cap)]^2]_{t-1}$				-0.1005686 (-0.77)	-0.2378874 $(-2.00)^{*}$
Intercept				-0.0126501 (-0.93)	0.0126765 (0.85)

[a]*Note:* *Significance at 10%. ** Significance at 5%. *** Significance at 1%.

In the restricted sample, there is a significant relationship between both variables in the short term. Among possible explanations for this result, it is worth noting that the economic crisis has triggered an important change in the evolution of per capita income over time, and this fact has reduced the significance of the relationship between both variables.

In accordance with Grubb *et al.* (2004) and, more recently, Doda (2013), the linkage is expected to be lower during periods of economic expansion than in a decline. By contrast, York (2012) proved that the linkage is stronger in periods of economic growth. In our dataset, the period between 1960 and 1980 is clearly characterized as a phase of economic expansion (see figure 2), and at the same time, pollution growth oscillates about 5%. According to table 4, in this period the strength of the relationship is greater than that obtained in the second period (1981-1993), when economic growth tends to be less intensive. Finally, we can observe an increase in the annual growth rates from 1994 to 2008, and the relationship is not significant. Thus, our results between 1960 and 1980 seem to be in line with York (2012). After this period, the model outcome coincides with Grubb *et al.* (2004) and Doda (2013).

As observed in table 4, the relationship is less significant in the last period, when regional taxes on emissions had been implemented. Therefore, fiscal policy could be one of the factors that have contributed to the decoupling of economic growth and environmental degradation to some extent. In order to evaluate whether or not there has been a significant change in the regional environmental performance after the implementation of fiscal policy, we have proposed an empirical analysis to test for the existence of stochastic convergence from 1995-2010.

5. Stochastic convergence in the short term

Stochastic convergence is a common tool used to evaluate the convergence of the pollution time series. It is based on the hypothesis that a random magnitude evolves according to a pattern. The seminal contribution was developed by Solow (1956) and transferred to the area of environmental research by Aldy (2006). In this section, we apply stochastic convergence to determine if regions which have applied emissions taxes comparatively reduce their pollution intensity[5] (Andalusia, Aragon, Castilla-La Mancha, Galicia and Murcia). In that case, taxes would be considered effective.

In Spain, green taxes are commonly implemented in the regional tier and more specifically, emissions taxes are exclusively applied by five regions[6]. This fact means there is an imbalance in environmental engagement across regions. However, carbon dioxide pollution is an externality whose effect crosses regional and national borders. For that reason, it should be mitigated through an overall response. As the possibility of an effective international agreement still remains far from reality, a national policy seems to be the best alternative.

The differences in environmental goals among regions could be the reason that compels certain regional governments to set emissions taxes, but if the hypothesis of convergence is accepted, stronger coordination across different jurisdictions will be necessary to abate pollution intensity throughout the country. On the other hand, in a non-convergence scenario, tax policies should be developed in each region which take into account the preferences of their citizens and their environmental requirements.

According to Barassi *et al.* (2008), a shock in a region involves a temporary deviation from stationary equilibrium. More precisely, the return to equilibrium is evidence of convergence. In order to test whether these effects are permanent, we implement panel data unit root tests, with the optimal number of lags determined by the Akaike Information Criterion. Regional data on greenhouse gas emissions are from the Pollution Register webpage, and data on per capita income is available from the National Statistics Institute (Instituto Nacional de Estadística, INE). Let the dependent variable be the expression of Carlino and Mills (1993), described in (5) and measured in tons of carbon dioxide equivalent over the period 1995-2010.

$$y_{jt} = \ln\left(\frac{CO_2/GDP_{jt}}{N^{-1}\left(\sum_{1}^{17} CO_2/GDP_j\right)} \right) \tag{5}$$

In equation (5), the index j =1…17 refers to region, and t =1…16 refers to year. Firstly, we perform the IPS test (Im, Pesaran and Shin, 2003) in case of spatial independence[7], by including a trend in the auxiliary regression. The model is represented as follows[8]:

$$\Delta y_{jt} = \eta_j + \beta_j t + \rho_j y_{jt-1} + \sum_{n=1}^{\rho_j} \varphi_{jt-i} \Delta y_{jt-n} + \varepsilon_{jt} \tag{6}$$

The null hypothesis assumes the existence of unit roots (non-stationarity). On the other hand, rejecting the null hypothesis means that territories return to pre-shock equilibrium

(Strazicich and List, 2003). Analytically, the IPS test is the average of ‘t’ unit root statistics. Unlike IPS, the null hypothesis of the Hadri test (2000) does not assess the existence of unit roots, but stationarity in an individual series. Barassi *et al.* (2008) point out that the LM Hadri test is an extension of the Kwiatkowski *et al.* test (KPSS, 1992) for panel data. The auxiliary regression is:

$$y_{jt} = d_{jt} + \mu_{jt} + u_{jt} \tag{7}$$

The qualitative variables d_{jt} and μ_{jt} represent geographical and time effects, respectively. Heteroscedasticity and autocorrelation consistent standard errors are distributed under the hypothesis of spatial independence. The Lagrangian test of Hadri is:

$$LM = \frac{1}{NT^2}\sum_{j=1}^{N}\sum_{t=1}^{T}\frac{\hat{S}_{jt}^2}{\hat{\sigma}_{uj}^2} \tag{8}$$

In this equation, N is the number of territories and T is the number of periods. $\hat{S}_{jt}^2$ is the sum of squared errors, and $\hat{\sigma}_{uj}^2$ is the variance.

In panel data, spatial independence is frequently rejected and for this reason, we might obtain inconsistent results. In order to overcome this problem, a second order test should be implemented. First, we must test for spatial dependence with the Pesaran test (2004):

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{j=1}^{N-1}\sum_{i=j+1}^{N}\hat{\rho}_{ji}\right) \tag{9}$$

$\hat{\rho}_{ji}$ is the autocorrelation of residuals from Dickey-Fuller individual regression. If the null hypothesis of spatial independence is rejected, we will need to implement the second order test. In that case, we will follow the proposal of Pesaran (2007) for an AR (p) specification error. This test, called CIPS, is the average of the individual unit root test:

$$\Delta y_{it} = a_i + b_i y_{it-1} + c_i \bar{y}_{t-1} + \sum_{j=0}^{p} d_{ij}\Delta\bar{y}_{t-j} + \sum_{j=1}^{p}\delta_{ij}\Delta y_{i,t-j} + e_{it} \tag{10}$$

Our empirical results are displayed in table 5. The null hypothesis of the IPS test is not rejected, and therefore, the hypothesis of convergence is strongly disproved. With regards to individual results, it is also rejected in line with the national outcome in most of the regions. However, in Aragon, the Canary Islands and Castilla-La Mancha, the empirical evidence leads us to reject the null hypothesis at a 5% significance level, and in Andalusia, at 10%. With respect to Hadri, convergence at a national level is rejected. Our regional results also show strong evidence against the null hypothesis which is consistent with national findings. In contrast, in

Andalusia, Aragon, Canary Islands, Castilla-La Mancha and Madrid the null hypothesis is accepted. Three of these regions implement pollution taxes, therefore, this could be partially due to tax effect, but there is insufficient evidence to support this hypothesis.

Table 5
IPS AND HADRI TESTS

	IPS	*p-value*	*lags*	H_{LM}	*p-value*
National result	-0.3486	0.3637		9.7032	0.0000
Andalusia	-1.5079	0.0658	1	-0.4432	0.6712
Aragon	-1.6828	0.0462	0	0.6793	0.2485
Asturias	1.1235	0.8694	1	4.7345	0.0000
Balearic Islands	1.6856	0.9541	1	3.8478	0.0001
Canary Islands	-3.0221	0.0013	0	0.1824	0.4276
Cantabria	-0.2640	0.3959	0	2.6627	0.0039
Castilla y Leon	1.5189	0.9356	0	3.5788	0.0002
Castilla-La Mancha	-2.1830	0.0145	0	1.0936	0.1371
Catalonia	2.3153	0.9897	0	5.4069	0.0000
Valencian Community	1.7454	0.9595	0	3.0032	0.0013
Extremadura	-0.0352	0.4860	0	2.3583	0.0092
Galicia	-0.5163	0.3028	0	3.0480	0.0012
La Rioja	0.0699	0.5279	1	1.4975	0.0671
Madrid	-0.9767	0.1644	0	0.4431	0.3288
Navarre	0.0688	0.5274	0	1.7546	0.0397
Basque Country	-0.3216	0.3739	0	2.9675	0.0015
Murcia	0.4451	0.6719	0	3.1923	0.0007

[a]*Note:* Optimal lags are selected attending to Akaike Information Criterion.

On the other hand, as Pesaran (2004) determines the existence of spatial dependence (p-value: 0.0148), we need to implement an alternative method. In the literature, we find a second order test that serves to prove non-stationarity, which we carried out for one and zero lags, selected through Akaike Information Criterion (1974). The test results indicate that there is not enough evidence to reject the null hypothesis of non-stationarity (table 6).

Table 6
STATIONARITY TEST WITH SPATIAL DEPENDENCE

No. lags	*Statistic*	*p-value*
0	-2.357	0.377
1	-2.344	0.398

[a]*Note:* the variable is the logarithm of the ratio between pollution intensity and its annual average.

Our empirical evidence, tables 5 and 6, shows that the hypothesis of stochastic convergence is not proven for the majority of the regions. The interpretation of these results as a whole leads us to confirm the non-existence of a common behaviour and the need for a differentiated policy.

However, given individual results, particularly those referring to Andalusia, Aragon and Castilla-La Mancha (three of the five regions with pollution tax, see Annex A), we can confirm that empirical evidence is uncommon. For those regions, pollution intensity reveals stable performance around a decreasing trend. Although we may consider this to be proof of the effectiveness of three of the five pollution taxes, the evidence is not strong enough to confirm the effectiveness of taxation.

6. Concluding remarks and political implications

If the Environmental Kuznets Curve hypothesis was undoubtedly proved in any context, pollution would be a temporary problem. From this point of view, political intervention to mitigate pollution would be unnecessary. Nevertheless, the meta-analysis of Lieb (2003:2) points out that empirical evidence of the EKC is 'only observed for flow and local pollutants: but not for stock and global pollutants'. The author also warns of the danger of considering pollution as a 'temporary problem in the course of economic growth'. Similarly, recent papers call on all governments to reinforce pollution abatement (through research and technological innovation in the production process) since it is a persistent problem and could potentially cause irreversible damage (Magnani, 2001 and Solomon *et al.*, 2009, among others).

An important point in this paper is the use of a methodology comprising a cointegration test and a regression model. The first enables us to overcome the problems associated with sample selection, and equation (4) gives us the chance to analyse the non-linear relationship between income and pollution.

Our results indicate that air pollution growth tends to decrease after passing an income turning point, in line with Cantos and Balsalobre (2011) and Esteve and Tamarit (2012b). Although these results lead to the acceptance of EKC and demonstrate the existence of a stable relationship between pollution and income in the short term, we should be cautious when evaluating this outcome. This is due to the unstable linkage in the long term and the fact that the income turning point is outside the sample, as obtained in Iwata *et al.* (2010). These facts prevent us from establishing a robust conclusion on the EKC and suggest that further research is needed. Definitely, the empirical evidence is barely conclusive.

One of the most important contributions of our investigation is the panel data unit root test. In the short term, we tested for the existence of regional stochastic convergence to evaluate the effectiveness of pollution taxes. It is also worth noting that Spanish environmental regulations (controls, taxes, etc.) differ across regions. In this paper, we focused on taxation, and for that reason, a general review of regional pollution taxes can be seen in Annex A.

Notably, although convergence is rejected, we obtained the opposite finding in four regions; Andalusia, Aragon, Canary Islands and Castilla-La Mancha. This issue denotes that these series are stationary around a decreasing trend. With the exception of the Canary Islands, the rest of them implement pollution taxes. Therefore, the tests outlined in Section 5 suggest that environmental regulation can stimulate a different performance in carbon dioxide emissions. Nevertheless, not all series corresponding to regions which implement pollution taxes are stationary and not all stationary series correspond to regions which tax emissions. On the basis of this evidence, it is not possible to confirm that taxes are effective.

In conclusion, the Engle-Granger approach seems to indicate that pollution and income are cointegrated (although the significance of the relationship in the long term has not been proven). However, this finding is questioned in view of our empirical outcome, as the sample size is not large enough. On the other hand, the study of stochastic convergence reveals that taxation does not have a great impact on pollution intensity (emissions per unit of GDP), since not all regions that apply pollution taxes tend to converge downwards.

As a consequence, the public sector must implement effective tax policies, so that environmental damage can be made internalized. The required green-oriented tax reform should include higher tax rates, a reduction of tax exemptions and an increase in the number of taxpayers in line with European taxation, as we can observe in the OECD/EEA database of instruments used for environmental policy and natural resource management. A well-designed taxation system would definitely encourage a change in private behaviour and reinforce environmental compliance.

Annex A: Air pollution taxes in Spain

Table A.1
SUMMARY OF AIR POLLUTION TAXES IN SPAIN

Region	Tax rates				
	NOx	SOx	CO_2	COV	NH_3
Andalusia (2004)	0-1000: 50 1000-3000: 80 3000-4000: 100 4000-5000: 120 > 5000: 140	0-1500: 33,33 1500-4500: 53,33 4500-6000: 66,67 6000-7500: 80,00 > 7500: 93,33	0-1000000: 0,05 1000000-3000000: 0,08 3000000-4000000: 0,10 4000000-5000000: 0,12 > 5000000: 0,14		
Aragon (2006)	0 a 100: 0 > 100:50	0 a 150: 0 > 150:50	a 100000: 0 > 100000: 0.2		
Castilla-La Mancha (2001)	0 a 500: 0 501 a 5000: 51 5001 a 10000 : 90 10001 a 15000: 120 > 15000: 150	0 a 500: 0 501 a 5000: 34 5001 a 10000: 60 10001 a 15000: 80 > 15000: 100			
Galicia (1996)	0 a 1000: 0 1000,01 a 40000: 33 40000,01 a 80000:36 > 80000: 42	0 a 1000: 0 1000,01 a 40000: 33 40000,01 a 80000:36 > 80000: 42			
Murcia (2006)	0-1000: 50 1000-3000: 80 3000-4000: 100 4000-5000: 120 > 5000: 140	0-1500: 33,33 1500-4500: 53,33 4500-6000: 66,67 6000-7500: 80,00 > 7500: 93,33		0-1000: 50 1000-3000: 80 3000-4000: 100 4000-5000: 120 > 5000: 140	0-100: 50 100-300: 80 300-400: 100 400-500: 120 > 500: 140

Source: own elaboration from regional legislation. [a]Data in €/ton. [b]Note: In Andalusia and Murcia, pollution is measured in pollutant units. 1 pollutant unit of CO_2 = 100.000 tonnes; 1 pollutant unit of NO_X = 100 tonnes; 1 pollutant unit of SO_X = 150 tonnes; 1 pollutant unit of COV = 100 tonnes; 1 pollutant unit of NH_3 = 10 tonnes.

Notes

1. Air pollution regional taxes have been implemented in five regions: Galicia (1995), Castilla La-Mancha (2001), Andalusia (2004), Murcia (2006) and Aragon (2006). The main characteristics of regional taxes are described in *OECD/EEA database on instruments used for environmental policy and natural resources management* and Gago and Labandeira (1997).
2. In addition, they assert that the relationship between pollution and economic growth does not have to be linear.
3. Another possible reason to explain the outcome can be the existence of structural changes in the economy over the last decades.
4. The speed at which deviation is corrected, when the dependent variable changes.
5. This variable represents emissions required to generate a unit of GDP. Analytically, it is equal to the rate between emissions and GDP.
6. Pollution data employed in Section 5 refers to GHG (greenhouse gas) emissions that include carbon dioxide and nitrogen oxide, among others. This latter is levied in all regional pollution taxes.
7. This methodology is adequate for high heterogeneity among countries. (Hall y Mairese, 2002).
8. Based on augmented Dickey-Fuller test.

References

Aldy, J. E. (2006), “Per capita carbon dioxide emissions: Convergence or divergence?”, *Environmental and Resource Economics,* 33: 533-555.

Aviral Kumar, T. and Shahbaz, M. (2013), “The environmental Kuznets curve and the role of coal consumption in India: cointegration and causality analysis in an open economy”, *Renewable and Sustainable Energy Reviews*, 18: 519-527.

Azomahou, T. Laisney, F. and Van, N. P. (2006)**,** “Economic development and CO2 emissions: A non-parametric panel approach”, *Journal of Public Economics*, 90: 347-1363.

Bai, J., and Ng, S. (2004), “A PANIC attack on unit roots and cointegration”, *Econometrica*, *72*(4): 1127-1177.

Barassi, M. R., Cole, M. A., and Elliott, R. J. (2008), “Stochastic divergence or convergence of per capita carbon dioxide emissions: re-examining the evidence”, *Environmental and Resource Economics*, 40(1): 121-137.

Cantos, JM. and Balsalobre, D. (2011), “Las energías renovables en la curva de Kuznets ambiental: una aplicación para España”, *Estudios de Economía Aplicada,* 29(2): 17-32.

Carlino, G. A., and Mills, L. O. (1993), “Are US regional incomes converging?: A time series analysis”, *Journal of Monetary Economics*, 32(2): 335-346.

Cavlovic, T. A., Baker, K. H., Berrens, R. P., and Gawande, K. (2000), “A meta-analysis of environmental Kuznets curve studies”, *Agricultural and Resource Economics Review*, *29*(1): 32-42.

DeJong, D. N., Nankervis, J. C., Savin, N. E., and Whiteman, C. H. (1992), “The power problems of unit root test in time series with autoregressive errors”, *Journal of Econometrics*, *53*(1): 323-343.

Díaz-Vázquez, R. (2009), ”The dissociation between emissions and economic growth: the role of shocks exogenous to the environmental Kuznets curve model”, *Applied Econometrics and International Development*, 9(2): 31-42.

Dickey, D. A., and Fuller, W. A. (1979), "Distribution of the estimators for autoregressive time series with a unit root", *Journal of the American Statistical Association*, *74*(366a):427-431.

Dickey, D. A., and Fuller, W. A. (1981), "Likelihood ratio statistics for autoregressive time series with a unit root", *Econometrica: Journal of the Econometric Society, 49*(4): 1057-1072.

Dinda, S.; Coondoo, D. and Pal, M. (2000), "Air quality and economic growth: an empirical study", *Ecological Economics*, 34(3): 409-423.

Dinda, S. (2004), "Environmental Kuznets curve hypothesis: a survey", *Ecological Economics*, *49*(4): 431-455.

Doda, B. (2013), "Emissions-GDP Relationship in Times of Growth and Decline", *Retrieved October*, *15*(2013): 110-19.

Ekins, P. (1997), "The Kuznets curve for the environment and economic growth: examining the evidence", *Environment and planning a*, *29*(5): 805-830.

Elliot, B. E., Rothenberg, T. J., and Stock, J. H. (1996), "Efficient tests of the unit root hypothesis". *Econometrica*, *64*(8):13-36.

Engle, R. F. and Granger, C. W. (1987), "Co-integration and error correction: representation, estimation, and testing", *Econometrica, 55*(2): 251-276.

EPER. Ministry of Agriculture and Environment. 'www.prtr.es'.

Esteve, V., and Tamarit, C. (2012a), "Is there an environmental Kuznets curve for Spain? Fresh evidence from old data", *Economic Modelling*, *29*(6): 2696-2703.

Esteve, V. and Tamarit, C. (2012b), "Threshold cointegration and nonlinear adjustment between CO_2 and Income: the environmental Kuznets curve in Spain, 1857-2007, *Energy economics* 34: 2148-2156.

Friedl, B. and Getzner, M. (2003), "Determinants of CO_2 emissions in a small open economy", *Ecological Economics*, 45(1): 133-148.

Gago, A. and Labandeira, X. (1997), "La imposición ambiental, Fundamentos, Tipología Comparada y Experiencias en la OCDE y en España", *Hacienda Pública Española,* 141/142: 193-219.

Gould, J. P., and Nelson, C. R. (1974), "The stochastic structure of the velocity of money", *The American Economic Review*, 64(3): 405-418.

Grossman, G. and Krueger, A. (1991), "Environmental impacts of a north American free trade agreement", *Working paper* n.º 3914, National Bureau of Economic Research. Cambridge, MA, November.

Grossman, G. and Krueger, A. (1994), "Economic growth and the environment" (No. w4634), *National Bureau of Economic Research.*

Grubb, M.; Muller, B., and Butter, L. (2004), "The relationship between carbon dioxide emissions and economic growth", *Oxbridge study on CO2-GDP relationships*.

Hadri, K. (2000), "Testing for stationarity in heterogeneous panel data", *The Econometrics Journal*, *3*(2): 148-161.

Hall, B. and Mairesse, J. (2002), "Testing for Unit Roots in Panel Data: An Exploration Using Real and Simulated Data", *Economics Department,* UC Berkeley.

Hong, S. H., and Wagner, M. (2008), "Nonlinear cointegration analysis and the environmental Kuznets curve", *Reihe Ökonomie/Economics Series*, 224, Institut für Höhere Studien (IHS).

Iglesias, J. I.; Carmona M., Golpe A. and Martín; J. M. (2013), "La curva de Kuznets y la emisión de CO_2 en España: 1850-2008", *Economía Industrial*, 389: 135-144.

Im, K. S., Pesaran, M. and H. Shin, Y. (2003), "Testing for unit roots in heterogenous panels", *Journal of Econometrics,* 115: 53-74.

Iwata, H., Okada, K., and Samreth, S. (2010), "Empirical study on the environmental Kuznets curve for CO_2 in France: the role of nuclear energy", *Energy Policy*, *38*(8): 4057-4063.

Kejriwal, M. and Perron, P. (2010), "Testing for multiple structural changes in cointegrated regression models", *Journal of Business and Economic Statistics*, 28: 503-522.

Kuznets, S. (1955), "Economic growth and income inequality", *The American Economic Review 45(1):* 1-28.

Kwiatkowski, D.; Phillips, P. C.; Schmidt, P., and Shin, Y. (1992), "Testing the null hypothesis of stationarity against the alternative of a unit root: How sure are we that economic time series have a unit root?", *Journal of econometrics*, 54(1):159-178.

Lieb, C (2003), "The Environmental Kuznets Curve - A Survey of the Empirical Evidence and of Possible Causes", *Discussion papers Series*. N.º391. University of Heidelberg.

Maddala, G. S. and Kim I-M. (1998), *Unit Roots, Cointegration, and Structural Change*, Cambrigde University Press. London.

Magnani, E. (2001), "The Environmental Kuznets Curve: development path or policy result?", *Environmental Modelling and Software*, *16*(2): 157-165.

Moon, H. R., and Perron, B. (2004), "Testing for a unit root in panels with dynamic factors", *Journal of econometrics*, 122(1): 81-126.

Newey, W. K. and West, K. D. (1994), "Automatic lag selection in covariance matrix estimation", *The Review of Economic Studies*, *61*(4): 631-653.

Ng, S. and Perron, P. (2001), "Lag Length Selection and the Construction of Unit Root Tests with Good Size and Power", *Econometrica*, 69: 1519-1554.

National Statistics Institute. 'www.ine.es'.

OCDE. The OECD/EEA database on instruments used for environmental policy and natural resources management, Database available on http://stats.oecd.org/

Panayotou, T. (1993), *Empirical tests and policy analysis of environmental degradation at different stages of economic development*, Geneva: International Labor Office, Technology and Employment Programme.

Pesaran, M. H. (2004), "General diagnostic tests for cross section dependence in panels", Cambridge *Working Papers in Economics 0435.* University of Cambridge.

Pesaran, M. H. (2007), "A Simple Panel Unit Root Test In The Presence Of Cross-section Dependence", *Journal Of Applied Econometrics* 22: 265-312.

Phillips, P. C. and Sul, D. (2003), "Dynamic panel estimation and homogeneity testing under cross section dependence", *The Econometrics Journal*, 6(1): 217-259.

Roberts, J. T., and Parks, B. C. (2007), "A climate of injustice: Global inequality, north-south politics, and climate policy", *Ethics & International Affairs,* 2(22): 229-230.

Roca, J., Padilla, E., Farré, M., and Galletto, V. (2001), "Economic growth and atmospheric pollution in Spain: discussing the environmental Kuznets curve hypothesis", *Ecological Economics*, *39*(1): 85-99.

Schwarz, G. (1978), "Estimating the dimension of a model", *Annals of Statistics,* 6(2): 461-464.

Sephton, P. and J. Mann (2013), "Further Evidence of an Environmental Kuznets Curve in Spain", *Energy Economics,* 36: 177 - 181.

Shahbaz, M., Jalil, A., and Dube, S. (2010), "Environmental Kuznets Curve (EKC): times series evidence from portugal", *MPRA Paper* No. 27443.

Shafik, N. and Bandyopadhyay, S. (1992), "Economic growth and environmental quality: time series and cross-country evidence" , *Working Papers,* 904, Washington D. C. World Bank.

Solomon, S.; Plattner, G. K.; Knutti, R., and Friedlingstein, P. (2009), "Irreversible climate change due to carbon dioxide emissions", *Proceedings of the National Academy of Sciences*, *106*(6): 1704-1709.

Solow, R (1956), "A contribution to the theory of economic growth", *The quarterly Journal of Economics*, *70*(1): 65-94.

Stern, D. I. (1998), "Progress on the environmental Kuznets curve?", *Environment and Development Economics*, *3*(2): 173-196.

Stern, D. I., and Common, M. S. (2001), "Is there an environmental Kuznets curve for sulfur?", *Journal of Environmental Economics and Management*, *41*(2): 162-178.

Stern, D. I. (2004), "The rise and fall of the Environmental Kuznets Curve", *World Development*, 32(8): 1419-1439.

Strazicich, M.C. and List, J.A. (2003), Are CO2 Emission Levels Converging Among Industrial Countries? *Environmental and Resource Economics,* 24(3): 263-271.

York (2012), "Asymmetric effects of economic growth and decline on CO_2 emissions", *Nature Climate Change*, 2(11): 762-764.

Resumen

Este artículo investiga el comportamiento dinámico de la contaminación atmosférica en España desde 1960 a 2010. Primero, evaluamos la relación entre el crecimiento económico y la contaminación a través de la Curva de Kuznets Ambiental. En segundo lugar, contrastamos la existencia de convergencia regional en la intensidad de la contaminación de 1995 a 2010, con el fin de analizar si los impuestos regionales destinados a reducir las emisiones han sido eficaces. Para la primera cuestión, nuestros resultados muestran una relación cuadrática, con el punto de inflexión fuera de la muestra. Para la segunda, se rechaza la convergencia aunque las regiones con impuesto parecen comportarse de forma distinta.

Palabras clave: comportamiento dinámico, impuesto sobre la contaminación.

Clasificación JEL: N50, O13, Q20