Determinants of CO2 emissions in open economies: testing the environmental Kuznets curve hypothesis (1970-2000)

Mota, Rui Pedro and Dias, João

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Determinants of CO_2 emissions in open economies: Testing the environmental Kuznets curve hypothesis (1970-2000)

Rui Pedro Mota, Environment and Energy Section, DEM, Instituto Superior Técnico
João Dias, Department of Mathematics, Instituto Superior de Economia e Gestão
Address: Avenida Rovisco Pais, 1, 1049-001 Lisboa, Portugal. Phone: +351 - 218 419 163, Fax: +351- 218 417 365, E-mail: rmota@ist.utl.pt.

Abstract

We address the problem of estimating an environmental Kuznets curve for CO_2 in open economies. The novelty is that we follow a time series approach. The objective is, first to answer a critique concerning the liability of Kuznets curves estimations when using cross-section data. For most of the countries analyzed here there is no evidence of a kuznet curve, though when using cross-section data there is a kuznet curve. Second, when using cross-section data it allows to test for other hypothesis concerning the functioning of the economy and pollution emissions. In particular we test hypothesis concerning the structure of the economy, the degree of openness of the economy, the influence of short-term fluctuations of economic growth and climate effects (when data is available). Moreover we test for the existence of a linear, a quadratic and a cubic relation between GNP and CO_2 emissions. Most evidence is in favour of a cubic relation for each country. For some countries the time series are not cointegrated, hence the model could not be estimated with econometric security.

Keywords: Environmental Kuznet curve, Open economies, Time series

1 Introduction

This paper intends to explain the evolution of the *per capita* carbon dioxide (CO_2) emissions in industrialized open economies. Namely, the relation between economic development and CO_2 emission is explored using data for Portugal, Austria, Japan and USA. Other countries were considered at first but since the results were not satisfactory their analysis is not presented here though some comments are made below. These are Ireland and France. In this paper, as Frield and Getzner (2003), the environmental Kuznets curve (EKC) hypothesis is tested for single countries instead on focusing on the analysis of cross-section data for a set countries. The arguments in favour of this approach will be put forward below.

This paper is structured as follows. Section 1.1 explains the EKC arguments, reviews previous efforts to test EKC for CO_2 emissions and introduces the basic model to test the EKC hypothesis along with other relations between emissions and economic growth. Section 1.2 deals with the relevant set of hypothesis applicable to a single industrialized country and extends the basic model to test for these hypothesis. Section 1.3 presents and discusses the arguments leading to the specific functional form used in the analysis of the countries. Section 2 presents the data used and briefly presents and comments on the relevant econometric theory to deal with the regressions considered here. Section 3 presents the results of the regressions for each country separately and concludes with some comments and compared results. Section 4 closes the paper with the discussion of the main results for environmental and economic policy and future work.

1.1 Environmental Kuznets curve

The environmental Kuznets curve (EKC) is a hypothesized relationship between various indicators of environmental degradation and income per capita. In the early stages of economic growth degradation and pollution increase, but beyond some level of income per capita, which will vary for different indicators, the trend reverses, so that at high income levels economic growth leads to environmental improvement. Typically, in cross-section studies, the logarithm of the indicator is modeled as a quadratic function of the logarithm of income (Stern, 2004; Stern et al., 1996; Bruyn et al.,1998; Roca et al., 2001).

The reasoning behind the EKC hypothesis has been put succinctly as follows by Panayatou, (1993)[1]: "At low levels of development, both the quantity and the intensity of environmental degradation are limited to the impacts of subsistence economic activity on the resource base and to limited quantities of biodegradable wastes. As agriculture and resource extraction intensify and industrialization takes off, both resource depletion and waste generation accelerate. At higher levels of development, structural change towards information-based industries and services, more efficient technologies, and increased demand for environmental quality result in leveling-off and a steady decline of environmental degradation".

This argument leads to a hypothesized relationship between environmental degradation and income per capita which takes the form of an inverted U. Such a relationship is called an "environmental Kuznets curve", after Kuznets who in 1955 hypothesized an inverted U for the relationship between a measure of inequality in the distribution of income and the level of income. If the EKC hypothesis held generally, it could imply that instead of being a threat to the environment, economic growth is the means to environmental improvement (Stern, 1996).

[1] in Panayatou (2003).

Panayotou (2003) has made a thorough review of empirical studies of the EKC hypothesis and in his appendix it is provided a summary of EKC studies. Roughly, the conclusion is that three specifications for EKCs have been mostly described in the literature: a linear, a quadratic (inverted U) and a cubic (N-shaped). One general functional form is

$$CO2_t = \beta_0 + \beta_1 y_t + \beta_2 y_t^2 + \beta_3 y_t^3 + \varepsilon_t, \tag{1}$$

where $CO2_t$ and y_t are, respectively, the CO_2 *per capita* emissions and GDP *per capita* in the year t. If $\beta_1 > 0$, $\beta_2 < 0$ and $\beta_3 = 0$ the economy followed a EKC in the period analyzed. However, from a theoretical point of view, the inverted-U relationship is less likely for CO2 emissions than for 'traditional' air pollutants. While these air pollutants have local effects, CO_2 emissions cause problems on a global scale, therefore, free-rider behavior might lead to a close relationship between carbon emissions and income at all levels of per capita income (Arrow et al., 1995; Friedl and Getzner, 2003).

The EKC concept emerged in the early 1990s with Grossman and Krueger's (1991)[2] pathbreaking study of the potential impacts of NAFTA and Shafik and Bandyopadhyay's (1992)[3] background study for the 1992 World Development Report. The EKC theme was, then, popularized by the World Bank's World Development Report 1992. After this there has been a growing number of studies to test the EKC hypothesis for several kinds of pollutants including SO_2, particulate matter, CO_2, clean water, deforestation, inputs of materials in the economy, NO_x, CO, $CFCs$, etc.

There are several major generic problems with hypothesis testing and estimation in relation to the EKC: the assumption of unidirectional causality from growth to environmental quality; the assumption that changes in trade relationships associated with development have no effect on environmental quality; and data problems and their implications (Stern et al. 1996). This paper intends to deal with the second and the third problems.

1.2 Testing other hypothesis

One criticism made to cross-section EKC studies is that the historical experience of the economies is not taken into account. For instance, international trade, environmental policy regulations or changes in structure of the economy influence the estimation of the EKC. Hence, the more promising approach is to investigate the time-series data of a single country which may be able to account for historical experience such as environmental policy, development of trade relations, or exogenous shocks such as the oil crisis rather than using reduced form equations of the EKC type presented above.

Besides the EKC curve (or other relations between CO_2 emissions and GDP) two other hypothesis are tested here. The first relates to trade (to test for the pollution haven hypothesis) and the second is a test for changes in the structure of the economy.

The pollution haven hypothesis states that countries that import most of their raw materials may be exporting environmental impacts to the countries with which they trade (Stern, 1996; Friedl and Getzner, 2003). From this point of view, imports should lead to a reduction in emissions. In the present study, the ratio of imports to GDP will be used as an explanatory variable to test for the pollution haven hypothesis.

[2] (in Stern, 2004)
[3] (in Stern, 2004)

As Panayotou mentioned, at high levels of development structural change towards information-based industries and services result in leveling-off and a steady decline of environmental degradation. To test this hypothesis, the service share (value added in the service sector in relation to GDP) is introduced as an explanatory variable.

The influence of short-term fluctuations of economic growth on CO_2 emissions, is also tested by incorporating the deviation of y_t trend in the model to regress. The hypothesis is that short-term fluctuations can lead to a significantly positive effect because an actual GDP above the long-term trend might lead to a short-term increase in CO_2 emissions even though the economy might be in the descending part of the EKC.

For Portugal's and Austria's analysis a climatic variable is included. The arguments is that while economic determinants may be the reason for long- and short-term developments in CO_2 emissions, climatic variations might be also influential (Friedl and Getzner, 2003). The variable included is the temperature deviation from the long-run temperature average, T_t. Friedl and Getzner (2003) argue, for Austria, that T_t can be hypothesized to exhibit a negative coefficient: in years with an above-average temperature, energy consumption (e.g. for heating) is lower, and thus lower CO_2 emissions can be expected. I argue that this is not a good hypothesis for countries in low latitudes since energy is going to be mostly spent in cooling and not heating. However, it also should be noted that mean temperature of a country is not a good variable if it refers to large countries such as USA, since spatial average of temperatures across latitudes has no clear meaning.

2 The model

The choice of the indicator of the CO_2 emissions is relevant for it can include important assumptions and influence the results of the estimations. Therefore, before considering different functional forms to explain the environment/income relationship, some comments are made on the correct dependent variable.

Friedl and Getzner (2003) identify four types of indicators commonly used for different pollutants or environmental degradation: (i) emissions *per capita*, (ii) emissions per GDP (pollution intensity), (iii) ambient levels of pollution (concentrations; impacts on a certain area), and (iv) total emissions. The most widely used in cross-country studies is the emissions *per capita*.

In this paper, the indicator of CO_2 emissions chosen is the emissions *per capita*. Ambient levels of pollution is important for local pollutants; pollution intensity does not depict very well the dynamics of CO_2 emissions (Friedl and Getzner, 2003) and also there is no *a priori* reason to commit to a relation between emissions and industrial output. Emissions *per capita* have the advantage of being consistent with the use of GDP *per capita*.

Having in mind the discussion above, the general model proposed is,

$$CO2_t = \beta_0 + \beta_1 y_t + \beta_2 y_t^2 + \beta_3 y_t^3 + \boldsymbol{\beta} \cdot \mathbf{V}_t + \varepsilon_t, \tag{2}$$

where $\mathbf{V}_t$ is a vector of other variables that influence the relationship between CO_2 emissions *per capita* and GDP *per capita,* associated with the respective vector of coefficients $\boldsymbol{\beta}$. In this case, $\mathbf{V}_t = (m_t, s_t, T_t, yd_t)$, where, m_t is the ratio of imports to GDP (%), s_t is the ratio of services to GDP (%), T_t is the deviation from long-term mean temperature (^{o}C), and yd_t is the deviation of GDP from trend-GDP.

Though most studies use a log functional form for testing the EKC relation here the functional form chosen is additive. When considering the log function form it is implicitly assumed that the explanatory variables affect the dependent variable in percentage change, whereas in the additive functional form this effect is in absolute values. This may be important for some cases, and may even be that the log functional form is the most appropriate in cross-section studies using a reduced form emissions/income equation, like equation (1). But for single country analysis where other explanatory variables are considered, one very important assumption when using the log functional is that all explanatory variables are essential. If one of them is zero the dependent variable is also zero. This does not makes sense in the cases analyzed here, hence the chosen functional form is additive.

3 Data and econometric methods

The data range used in this paper is 1970-2000. As much as possible the data used was taken from the same source. Hence, the two main sources were the United Nations Statistics Division[4] and the World Bank's Environmental Economics and Indicators (green accounting)[5]. The World Bank's calculations of genuine savings (or adjusted net savings) provided the time-series for CO_2 emissions and the population for the various countries used. The data for CO_2 emissions was estimated by the CDIAC[6]. All the other economic variables were provided by the United Nations Statistics Division, namely, the GDP, imports and value added from the service sector (all variables are at constant 1990 prices in national currency). The service sector includes wholesale, retail trade, restaurants and hotels; transport, storage and communication; and other activities.

The deviation of GDP from trend-GDP was constructed by means of a linear autoregressive model and it is the real value minus the estimated. If yd_t is positive (negative) this means that in that year the GDP *per capita* was higher (lower) then its trend.

The time series of deviation from long-term mean temperature was obtained for Portugal and Austria only. This time-series is available on the State of the Environment Report of 2003 (Relatório de Estado do Ambiente) from the Environment Institute (Instituto do Ambiente)[7]. The data for the deviations of the mean temperature for Austria was kindly provided be Michael Geztner.

3.1 Basic tests used

The EKC is an essentially empirical phenomenon, but most of the EKC literature is econometrically weak (Stern, 2004). In particular, little or no attention has been paid to the statistical properties of the data used and little consideration has been paid to issues of model adequacy such as the possibility of omitted variables bias (Stern, 2004). Most studies assume that, if the regression coefficients are significant and have the expected signs, then an EKC relation exists. However, one of the main purposes of doing econometrics is to test which apparent relationships are valid and which are spurious correlations. For instance, in this paper some EKC relations were obtained though in the end the series were not cointegrated and so the relations were spurious.

[4] http://unstats.un.org/unsd/snaama/dnllist.asp
[5] http://lnweb18.worldbank.org/ESSD/envext.nsf/44ByDocName/GreenAccountingAdjustedNetSavings
[6] http://cdiac.esd.ornl.gov/home.html
[7] http://www.iambiente.pt/

3.1.1 Stationarity and unit root - ADF test

Basically, the approach followed here is to first check whether the OLS and the usual tests on the regression results hold for the regressions produced. Hence, the order of integration of the time series is tested by using the augmented Dickey-Fuller (ADF) test with constant and time trend, starting with the variable in differences with lags of order 3. For all the series analysed the order the lags revealed as sufficient to conclude about the order of integration and it could be rejected for almost all tests made.

At each step, the lag of the higher order is rejected using the t-statistic as long as no autocorrelation is introduced in the regression. The calculated t-statistic of coefficient of the lagged variable is compared with the critical values using the Dickey-Fuller table of critical asymptotic values. The null hypothesis of the existence of a unit root, or of the non stationarity of the time series, is rejected whenever the calculated t-statistic is higher than the critical value at a given level of significance. So, the time series is considered stationary if this calculated t-statistic is higher than the critical value.

For all the countries presented here, the CO_2 *per capita* emissions time-series revealed to be integrated of order one I(1) along with the ratio of imports to GDP, the ratio of services to GDP and the deviation of GDP from trend-GDP. The two time-series of deviation from long-term mean temperature are I(0). For the countries presented here the variables involving different forms of GDP were also I(1). For instance, the ADF test applied to the Ireland's GDP time-series revealed the it was I(0). Also, the y_t^2 and y_t^3 time series are I(0) meaning that the regression of the CO_2 emissions with terms involving GDP is not accurate. Along with this, the Engle-Granger (EG) test for cointegration implies that these time series are not cointegrated for Ireland. Thus, the regressions made for the EKC in Ireland were spurious.

3.1.2 Cointegration - EG test

Another test used is the Engle-Granger test for cointegration, which basically consists of applying the ADF test to the residuals of a regression. If the time-series of residuals is I(0) then it can be concluded that the variables in the regression are cointegrated and at a given level of significance the presence of a spurious relation can be rejected. So, in order to have an acceptable regression it is sufficient that at least one of the explanatory variables is integrated of the same order of that of the dependent variable and the variables used are cointegrated. Applying the ADF test to the residuals of a regression implies that the computed t-statistic values must be compared not with the critical values of the ADF table but with the critical values in a EG table. For instance, the Austria's CO_2 and GDP time series are not cointegrated however the cubic and quadratic emission/income relations could be estimated since these are cointegrated (see table 3.2.2).

The method used here is to test for cointegration on the regressions that gave acceptable results at first. This choice is made since the EG test needs the residuals of the regression, so it is possible to reject some models before the cointegration test.

3.1.3 Structural breaks - Chow test

In the case of Portugal's CO_2 emissions time series, a structural break in the year 1988 can be readily identified (see figure 3.1.1). In this case, the test for the existence of a breakpoint the usual Chow test is applied. The problem of structural breaks is a relevant one for it can imply large biases on the regression results and on the tests carried. This is true specially for unit root tests. What should be done in this case is to apply the Perron test for unit roots with structural breaks. This tests for the existence of unit roots in the case of a structural break in the time-series. The structural break may be responsible for a change in the intercept term, for a change in the coefficients or both. Perron designed tests for unit roots and cointegration for these three cases, and calculated its critical values. The test turned out to be an extension of the ADF test incorporating a term related to the structural break.

In the analysis carried here the effects of the structural breaks on the regressions and on the unit root and cointegration test is acknowledge though in particular the Perron test is not applied. Also, in this paper, the power of the regressions and of the tests is somewhat restricted to the few degrees of freedom available. The data is only for 1970-2000. Hence, for the rest of the analysis, whenever there is no evident structural break on the time series for CO_2 emissions, it is assumed that there is no structural break. For the case of Portugal's CO_2 emissions the Chow breakpoint is applied, but additionally it is assumed that the structural break only affects the intercept term. This way a dummy variable for the year 1988 is introduced and the model is then regressed.

4 Countries' results

4.1 Portugal

The analysis starts by searching for the usual EKC, i.e., estimate equation (1). The representations of the relation of CO_2 emission with GDP are usually done in two ways, as in figure 3.1.1 and figure 3.1.2. In figure 3.1.1 the CO_2 pollution intensity of GDP is presented and a positive trend can be recognized. This means that in the period 1970-2000 the CO_2 emissions were growing at a higher rate than the income growth.

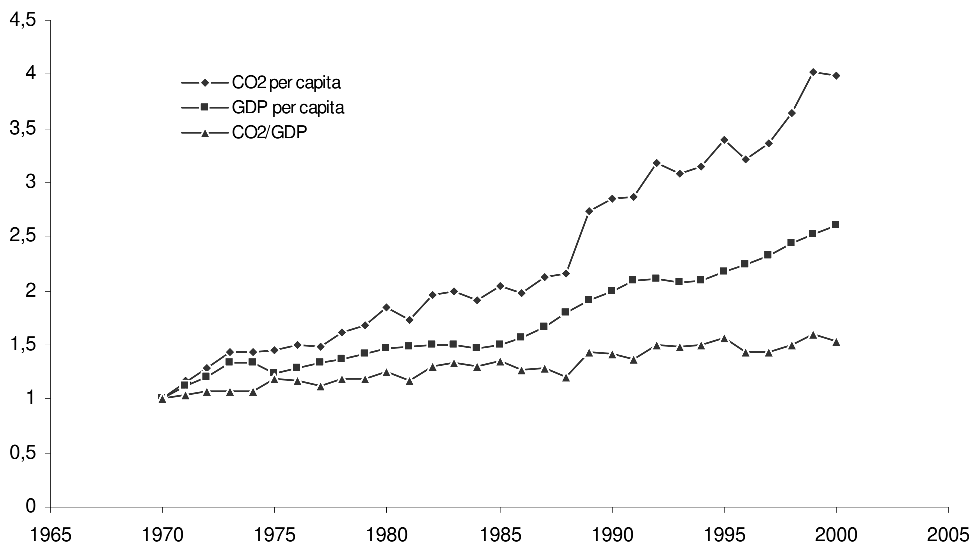

Figure 3.1.1: Evolution of *per capita* CO_2 emissions, GDP and intensity of CO_2 in the GDP (Index 1970=1).

In figure 3.1.2 it is presented a plot of the CO_2 emissions with GDP disregarding the evolution in time. This figure hints at a linear relation between emissions and income.

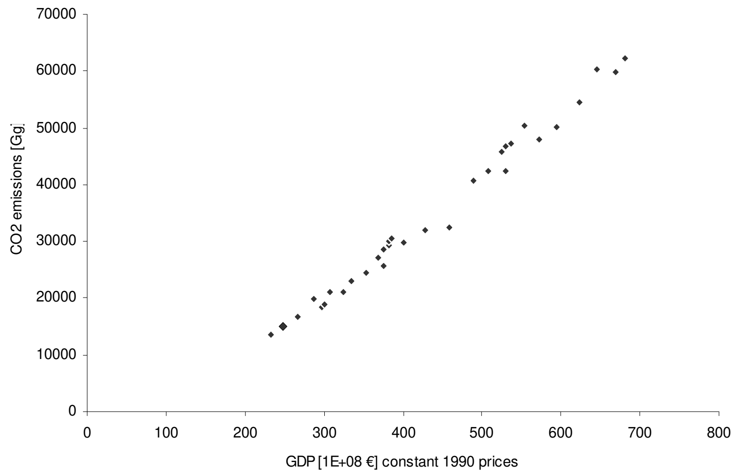

Figure 3.1.2: Relation of CO_2 emissions with GDP.

The relative evolution of the time series used in the regressions is presented in figure 3.1.3. Testing for the stationarity of the time-series in figure 3.1.3 using the ADF test, the conclusion is that all the variables are I(1) except for the deviation from the mean temperature which is I(0).

From figure 3.1.1 or 3.1.3 it can be seen that there exists a jump of the emission values around 1988. This is probably due the fact that around that time the first European funds were starting to be applied in Portugal. These funds were specially applied to road and highway constructions, having the almost certain impact of rising CO_2 *per capita* emissions. Also, at 1987 the portuguese governement had its first absolute majority which created conditions for the stabilization of the economy, namely lower interest rates, which has a direct impact on the households' consumption rate and an indirect impact on CO_2 *per capita* emissions.

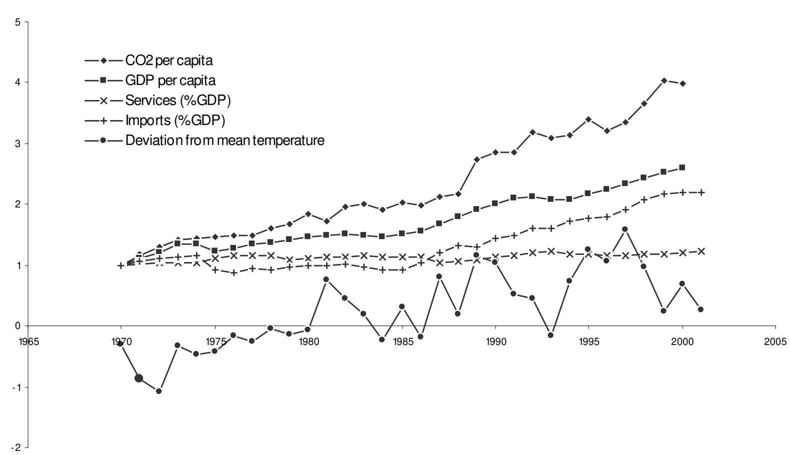

Figure 3.1.3: Relative evolution of the time series considered in the regressions. (Index, 1970=1).

Thus, the Chow test is applied for the hypothesis of a breakpoint on the CO_2 *per capita* emissions in the year 1988. The results are presented in table 3.1.1.

Explanatory Variables	CO_2 emissions *per capita*		
	1970-2000	1970-1988	1989-2000
Constant$\times 10^{-2}$	-0.154710^{***}	-0.109269^{***}	-0.125431^{**}
	(-12.1328)	(-3.81746)	(-2.08313)
$y_t \times 10^{-5}$	0.113508^{***}	0.100364^{***}	0.108852^{***}
	(40.4754)	(12.7001)	(10.3280)
Adj. R^2	0.982006	0.899042	0.905715
Schwarz B.I.C.	-221.425	-137.066	-84.2200
F-Test	1638.26	161.292	106.668
Durbin-Watson	1.68551	1.08701	1.87448
n	31	19	12
Chow F-statistic		1.56683	
Constant	-0.276841^{***}	-0.171598^{***}	-0.322851^{***}
	(-22.3062)	(-17.9396)	(-8.83374)
$time \times 10^{-5}$	0.141205^{***}	0.0879786^{***}	0.164346^{***}
	(22.5845)	(18.2023)	(8.96886)
Adj. R^2	0.944348	0.948324	0.878373
Schwarz B.I.C.	-203.924	-143.428	-82.6922
F-Test	510.061	331.323	80.4404
Durbin-Watson	0.587404	1.59534	1.52028
n	31	19	12
Chow F-statistic		40.21959^{***}	
Constant$\times 10^{-2}$	-0.111647	0.0968351	2.5645
	(-0.461556)	(0.132897)	(0.285308)
$y_t \times 10^{-5}$	-0.0556215	0.0137481	-1.14843
	(-0.394867)	(.020952)	(-0.241063)
$y_t^2 \times 10^{-9}$	0.302360	0.370922	1.57934
	(0.979957)	(0.204296)	(0.191620)
$y_t^3 \times 10^{-13}$	-0.191936	-0.474909	$-.743122$
	(-0.917818)	(-0.287445)	(-0.157541)
$m_t \times 10^{-4}$	0.126472	-2.00332	1.12669^{**}
	(0.840412)	(-0.687579)	(2.22474)
$s_t \times 10^{-4}$	0.402362^{***}	-0.175335	0.270878
	(2.81189)	(-0.595114)	(0.645140)
$yd_t \times 10^{-6}$	-0.291102^{**}	$-.425300^{**}$	0.707013
	(-2.06841)	(-2.31995)	(0.953410)
Adj. R^2	0.987147	0.963514	0.941539
Schwarz B.I.C.	-220.988	-142.683	-85.0344
F-Test	385.005	80.2235	30.5263
Durbin-Watson	2.37257	2.44445	2.81175
n	31	19	12
Chow F-statistic		3.28982^{**}	

Table 3.1.1 - Results of the Chow test to several models for the CO_2 emissions. In brackets it is presented the value of the t-statistic. *** - significant at 1%, ** - significant at 5%, * - significant at 10%.

The Chow test applied to the relation of CO_2 emissions and GNP gives a value of the Chow F-statistic of 1.56683, which is lower than the critical F value at the significance level of 5%. Thus, the null hypothesis of structural stability cannot be rejected and the regressions for 1970-1988 and 1989-2000 can be considered as the same. The second Chow test is applied to a simple autoregressive trend model, following Frield and Getzner (2003), and indicates a clear structural break in the year 1988 at the significance level of 1%.

Next, the Chow breakpoint test is applied to the general cubic regression and the value of the Chow F-statistic is higher than the critical value at the significance level of 5%. Hence, this indicates the existence of a structural break of this relation in the year 1988. The Chow test was also applied to the regression of the linear general model and the conclusion is that at the significance level of 5% the relation exhibits a breakpoint in the year 1988.

The conclusions are that, when testing for the linear relation of CO_2 *per capita* emissions with *per capita* GNP there is no breakpoint. However, when testing the general model - linear and cubic - there is a breakpoint in the year 1988. Assumig that this structural break only affects the intercept term of the regressions allows for the regression of the general models using the entire time series (1970-2000) as long as a dummy variable X_t accounting for the changes in 1988 is incorporated.

Explanatory Variables	CO_2 emissions *per capita*		
	$1970-2000$	$1970-1988$	$1989-2000$
Constant$\times 10^{-2}$	-0.358315^{***}	0.0712445	0.333108
	(-5.44084)	(0.408918)	(1.12282)
$y_t \times 10^{-6}$	0.857562^{***}	1.00215	-0.890865
	(8.81784)	(6.69543)	(-1.10324)
$m_t \times 10^{-4}$	0.240162^{***}	-0.340093	1.22424^{**}
	(2.51821)	(-1.27893)	(2.53335)
$s_t \times 10^{-4}$	0.421382^{***}	-0.156403	0.109793
	(3.10964)	(-0.579820)	(0.398164)
$yd_t \times 10^{-6}$	-0.304909^{**}	-0.325102^{**}	1.08690^{*}
	(-2.25456)	(-2.53998)	(1.60506)
Adj. R^2	0.987569	0.964326	0.942912
Schwarz B.I.C.	-223.699	-144.376	-85.6431
F-Test	596.849	122.641	46.4210
Durbin-Watson	2.34617	2.06010	2.27764
n	31	19	12
Chow F-statistic		4.05471^{**}	

Table 3.1.1 (Cont.) - Results of the Chow test to the linear general model. In brackets it is presented the value of the t-statistic. *** - significant at 1%, ** - significant at 5%, * - significant at 10%.

The following table presents the results of the testing of the model in equation (1) considering cubic, quadratic and linear relations between CO_2 emissions and GDP.

Explanatory variables	CO_2 emissions *per capita* 1970-2000		
	Cubic	Quadratic (EKC)	Linear
Constant$\times 10^{-2}$	-0.00660935	-0.124289^{**}	-0.154710^{***}
	(-0.032290)	(-2.13604)	(-12.1328)
$y_t \times 10^{-6}$	0.173970	0.995225^{***}	0.0280436^{***}
	(0.124833)	(3.79330)	(40.4754)
$y_t^2 \times 10^{-9}$	0.198810	0.0150711	
	(0.646740)	(0.536190)	
$y_t^3 \times 10^{-13}$	-0.132013		
	(-0.600287)		
Adj. R^2	0.981122	0.981553	0.982006
SSR$\times 10^{-06}$	0.887913	0.899763	0.909002
Schwarz B.I.C.	-218.355	-219.866	-221.425
F-Statistic	520.714^{***}	799.147^{***}	1638.26^{***}
Durbin-Watson	1.67717	1.68216	1.68551
n	31	31	31

Table 3.1.2 - Regressions of various relations of CO_2 emissions and GNP, including a direct test of the EKC hypothesis. In brackets it is presented the value of the t-statistic. *** - significant at 1%, ** - significant at 5%, * - significant at 10%. No superscript in the DW statistic indicates no autocorrelation, $^{+}$ indicates positive autocorrelation and $^{+/-}$ indicates inconclusive test, with significance of 5%. These apply for the rest of the tables.

The cubic form of equation (1) is rejected for Portugal since no variable is significant. The quadratic model is a direct test of the EKC hypothesis, and the existence of an EKC for Portugal is rejected since the term y_t^2 is not significative. The linear model, as expected, is the most appropriate to describe the relation between CO_2 emissions *per capita* and GDP *per capita*. The estimation of this equation is depicted in figure 3.1.4 comparing with the real data.

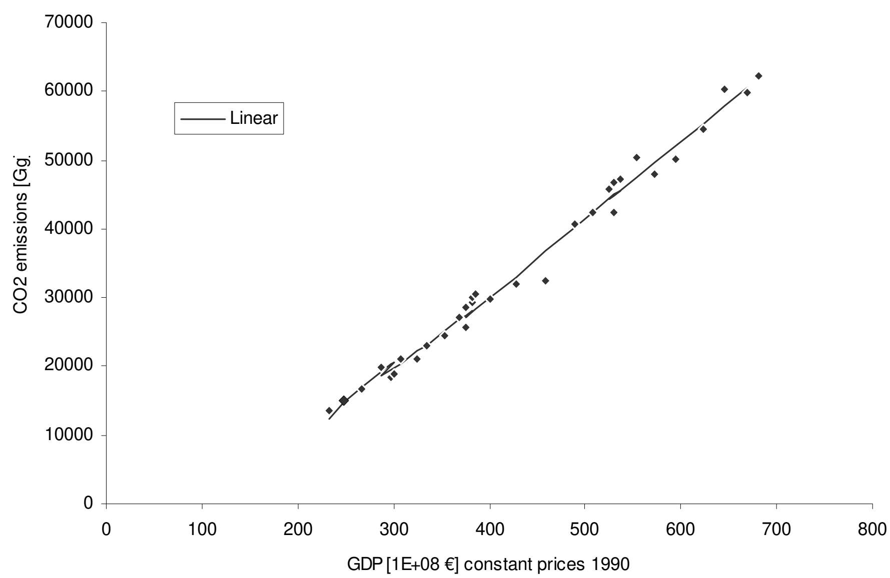

Figure 3.1.4: Comparison of the linear model with the real data.

Next, the general model in equation (2) is estimated, also considering cubic, quadratic and linear relations between CO_2 emissions and GDP. In the general cubic model, all variables are significant, at least at the significance level of 10%, except the deviations for the long-term mean temperature. At the 5% level of significance the only variables relevant to explain CO_2 *per capita* emissions are those related with GDP *per capita*, including the deviation of GDP from trend-GDP.

The general EKC is rejected for Portugal since, again, the y_t^2 is statistically zero. Finally, in the general linear model, all variables excluding the deviations for the long-term mean temperature are significant at 5% level of significance. Note that for all of the three general models the variable testing the breakpoint in 1988 is significant.

Explanatory Variables	CO_2 emissions *per capita* 1970-2000		
	Cubic	Quadratic (EKC)	Linear
Constant$\times 10^{-2}$	-0.729818^{***}	-0.167555^{*}	-0.292803^{***}
	(-2.56400)	(-1.40415)	(-4.15941)
$y_t \times 10^{-5}$	0.475644^{**}	0.0458108^{*}	0.0800906^{***}
	(2.35253)	(1.58298)	(6.87553)
$y_t^2 \times 10^{-9}$	-0.950442^{**}	0.0481025	
	(-2.03607)	(1.29062)	
$y_t^3 \times 10^{-13}$	0.703941^{**}		
	(2.14503)		
$m_t \times 10^{-5}$	2.25214^{*}	0.890195	2.0777^{**}
	(1.61389)	(0.666111)	(2.11466)
$s_t \times 10^{-4}$	0.196685^{*}	0.293694^{**}	0.351600^{**}
	(1.36296)	(1.99282)	(2.47059)
$T_t \times 10^{-4}$	-0.127513	-0.284663	-0.257761
	(-0.189593)	(-0.395917)	(-0.353779)
$yd_t \times 10^{-5}$	-0.601214^{***}	-0.0417079^{***}	-0.0384245^{**}
	(-3.91738)	(-3.04840)	(-2.81943)
$X_t \times 10^{-3}$	0.731372^{***}	0.342068^{**}	0.293841^{**}
	(3.31020)	(2.52424)	(2.22516)
Adj. R^2	0.990641	0.989176	0.988876
SSR$\times 10^{-6}$	0.358667	0.433680	0.465088
Schwarz B.I.C.	-223.820	-222.594	-223.227
F-Test	397.942^{***}	392.655^{***}	445.464^{***}
Durbin-Watson	$2.59668^{+/-}$	$2.40604^{+/-}$	$2.31146^{+/-}$
n	31	31	31

Table 3.1.3 - Results of the regressions of the general model for the CO_2 emissions in Portugal. In brackets it is presented the value of the t-statistic. *** - significant at 1%, ** - significant at 5%, * significant at 10%.

The next table presents the results for the cointegration tests made for the linear model, and for the general cubic and linear models.

Explanatory variables			
	CO_2 and GNP	General model	
	Linear	Cubic	Linear
Constant$\times 10^{-4}$	-0.402533	-0.103663	-0.136644
	(-0.571616)	(-0.242760)	(-0.246321)
res_{t-1}	-0.865031^{***}	-1.32671^{***}	-1.15865^{***}
	(-4.58142)	(-7.20445)	(-6.13920)
$time \times 10^{-6}$	2.14878	0.586046	0.660126
	(0.567618)	(0.255484)	(0.221701)
Adj. R^2	0.395856	0.632551	0.551799
Schwarz B.I.C.	-212.826	-227.749	-219.884
F-Statistic	10.5009	25.9613	18.8516
Durbin-Watson	1.94298	2.16671	2.09931
n	30	30	30

Table 3.1.4 - Results of the Engel-Granger test for the 3 relevant models. The coefficient associated to res_{t-1} should be tested for significance using the critical values of the Engle-Granger table. Based on the Engle-Granger table: *** - significant at 1%, ** - significant at 5%, * - significant at 10%.

With the results above, for the three models tested we reject the null hypothesis that the residuals are not stationary at the level of significance of 1%, meaning that the residuals are integrated of degree zero, I(0). Hence we can conclude that the series are cointegrated and since we have also seen that they are all I(1), we can safely use the usual OLS estimator and the usual tests.

Now, looking at the sign of the coefficients of table 3.1.3, it is possible to reject the pollution haven hypothesis for Portugal. The ratio of imports to GDP has a positive effect on *per capita* CO_2 emissions. This means that Portugal is not importing products that impose high CO_2 emissions on other countries. Unexpectedly, at first sight, the ratio of services to GDP has a positive coefficient, meaning that the services sector in Portugal contributes for the increase in CO_2 emissions in Portugal. However, as is mentioned in section 2, transports are part of the definition of services, thus possibly explaining this positive coefficient. The negative sign associated with the deviation of GDP from trend-GDP is not expected and is difficult to interpret. A higher than the trend GDP in one year reduces the *per capita* CO_2 emissions.

It is interesting to note that the general cubic and linear models are quite different in the sense that in the cubic model, all the variables are related to *per capita* income. The general cubic model explains CO_2 emissions with income related variables and the general linear model includes variables relate to the structure and the openness of the economy. The next figures present the estimations of CO_2 *per capita* emissions using these two models (after excluding the non-significant terms) in comparison to the "real" data. Note that both the models account well for the breakpoint in 1988.

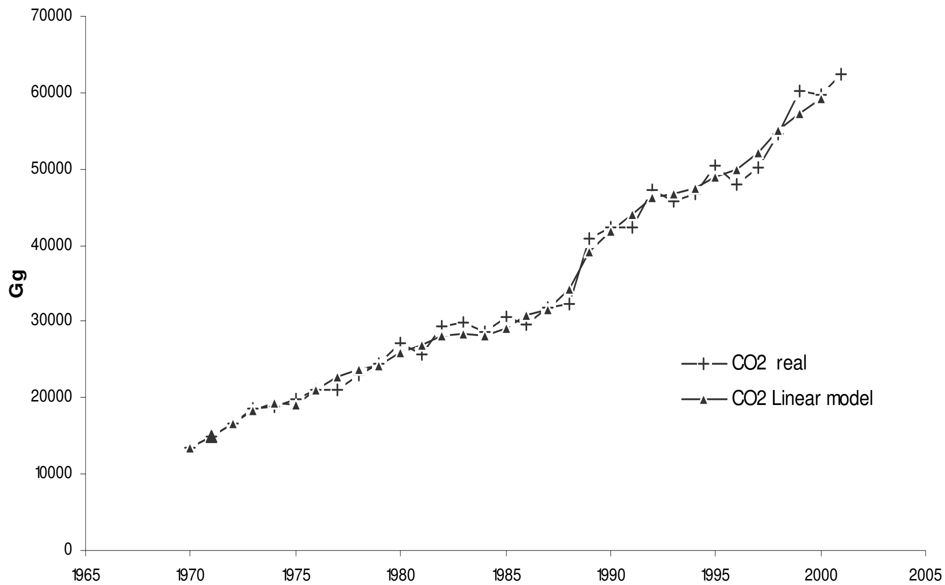

Figure 3.1.5: Comparison of the general linear model with the data for CO_2 emissions.

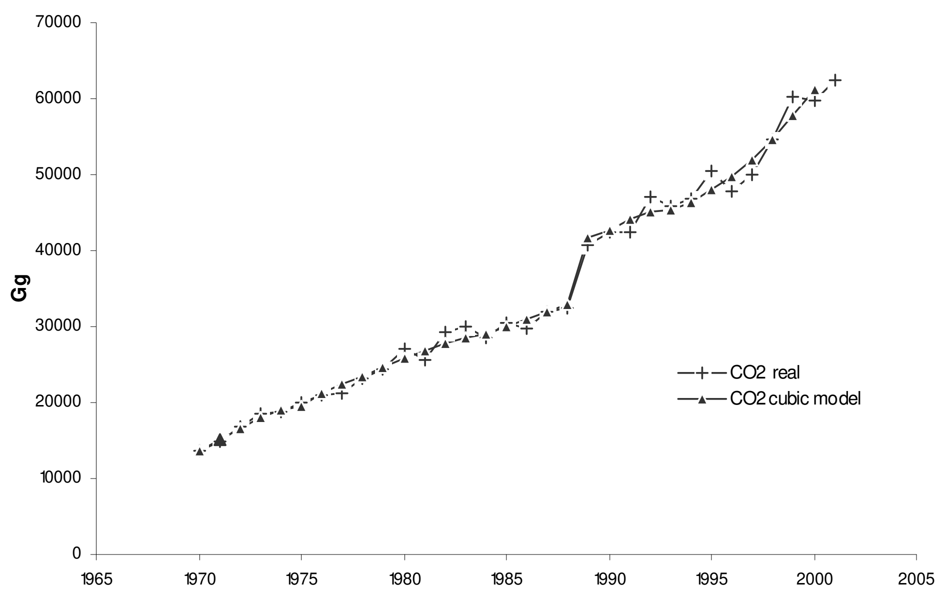

Figure 3.1.6: Comparison of the general cubic model with the data for CO_2 emissions.

4.2 Austria

The Austria economy was chosen for this analysis for two main reasons. First, it is a European high income developed country, and second this paper is based on the idea of a similar study applied to Austria by Frield and Getzner (2003) and it would be interesting to compare the results.

Again, trying to visualize the EKC for the Austrian economy in figures 3.2.1 and 3.2.2, it is depicted the CO_2 intensity of the GDP and the plot of the CO_2 emissions with GDP disregarding the evolution in time. Looking at figure 3.2.1 it is possible to see the CO_2 intensity of the GDP of GDP going down, meaning that the income growth is being decoupled of the CO_2 emissions. Also, there is no clear hint of any structural break on the CO_2 *per capita* emissions time series. Friedl and Getzner (2003), when analyzing the emissions of CO_2, discuss the possibility of a structural break between 1973 and 1975 due to the oil price shock and the "general awareness of the growing scarcity of energy resources". They then apply the Chow test for the year 1974 and conclude for the existence of a breakpoint. Then, they estimate the model but in the end they just use a dummy, $D75$, trying to account for the structural break. The cubic extended model they present does not incorporate the dummy variable, so the test for the structural break was not relevant for the tested model in spite of the relevance it appeared to have in previous sections.

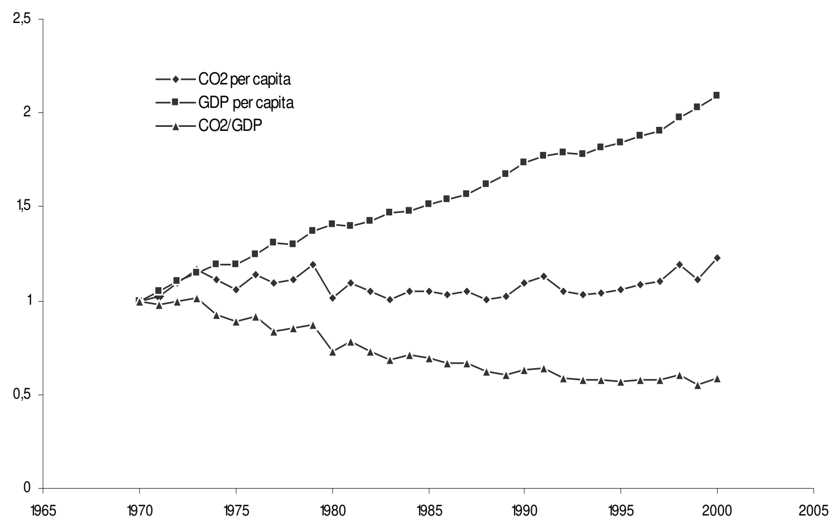

Figure 3.2.1: Evolution of *per capita* CO_2 emissions, GDP and intensity of CO_2 in the GDP (Index 1970=1).

So, Friedl and Getzner procedure can be criticized due to the fact that they acknowledge the existence of the structural break, and this information does not have any influence on the cubic extended model they estimate, which they conclude is the most appropriate to describe the CO_2 emissions. Also, using a dummy variable, as Friedl and Getzner do, only accounts for structural breaks that only changes the intercept term, and looking at the CO_2 emissions in fig 3.2.1 this hints more at the possibility of changes in the coefficient than changes in the intercept term.

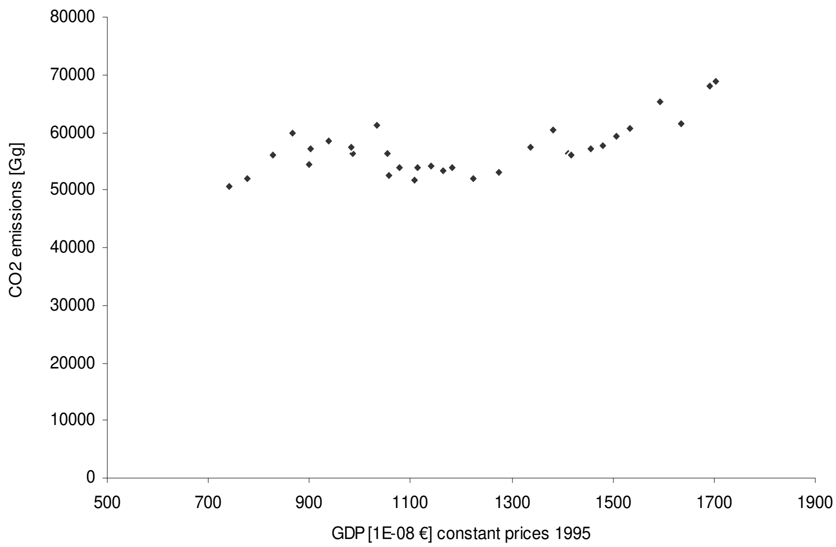

Figure 3.2.2: Relation of CO_2 emissions with GDP.

In the analysis carried here I have no *a priori* reason to believe that there are any other breakpoints in the CO_2 emissions in Austria than that due to the oil price shock around 1974. Since, the period of analysis here is 1970-2000, if the Chow test is applied to the year 1974 the degrees of freedom would not allow for safe conclusions. With this in mind I do not test for structural breaks of the CO_2 emissions in Austria as it was done for Portugal where a clear breakpoint could be seen simply by looking at figure 3.1.1 and some plausible reasons for the breakpoint were known.

From figure 3.2.2 it can be seen that probably the best model to describe the relation between CO_2 emissions and GDP is the cubic model.

In figure 3.3.3 are depicted the time series used in the analysis of the Austrian economy. Again, after applying the ADF test it is possible to conclude that all the time series are I(1), at the level of significance of 5%, except for the deviation of the mean temperature which is I(0).

The analysis carried here is the same has in the previous subsection for the Portuguese case.

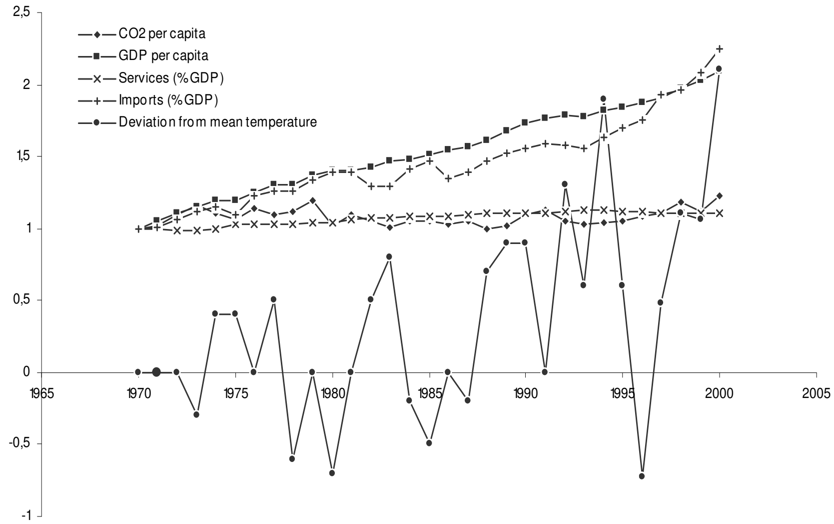

Figure 3.2.3: Relative evolution of the time series considered in the regressions. (Index, 1970=1).

In the following table are the results of the regressions of the model in equation (1)relating *per capita* CO_2 emissions with *per capita* GNP for the Austrian economy.

Explanatory variables	CO_2 emissions *per capita* 1970-2000		
	Cubic	Quadratic (EKC)	Linear
Constant$\times 10^{-2}$	-0.017492^{***}	0.010726^{***}	0.691459^{**}
	(-2.50049)	(5.96031)	(18.3919)
$y_t \times 10^{-6}$	5.32252^{***}	-0.487291^{**}	0.0287700
	(3.74152)	(-2.03064)	(1.19421)
$y_t^2 \times 10^{-9}$	-0.371369^{***}	0.0168074^{**}	
	(-3.93457)	(2.16021)	
$y_t^3 \times 10^{-14}$	0.843188^{***}		
	(4.12156)		
Adj. R^2	0.442814	0.124675	0.014006
SSR$\times 10^{-05}$	0.244859	0.398914	0.465398
Schwarz B.I.C.	-202.632	-196.784	-196.111
F-Statistic	8.94732^{***}	3.13649^{**}	1.42614
Durbin-Watson	1.91387	$1.33919^{+/-}$	1.15687^{+}
n	31	31	31

Table 3.2.1 - Direct tests of various relations of CO_2 emissions and GNP, including a test of the EKC hypothesis. In brackets it is presented value of the t-statistic. *** - significant at 1%, ** - significant at 5%, * - significant at 10%.

The linear model is clearly rejected since the y_t is not significant at the level of significance of 10%. The quadratic model implies the rejection of the EKC hypothesis for Austria since the sign of the term y_t^2 is positive. Comparing the SSR, the Schwarz information criterion, the F-statistic and the Durbin-Watson test for autocorrelation, this implies that the cubic model gives the best econometric results. In the next figures the fitting to data of the cubic model is presented.

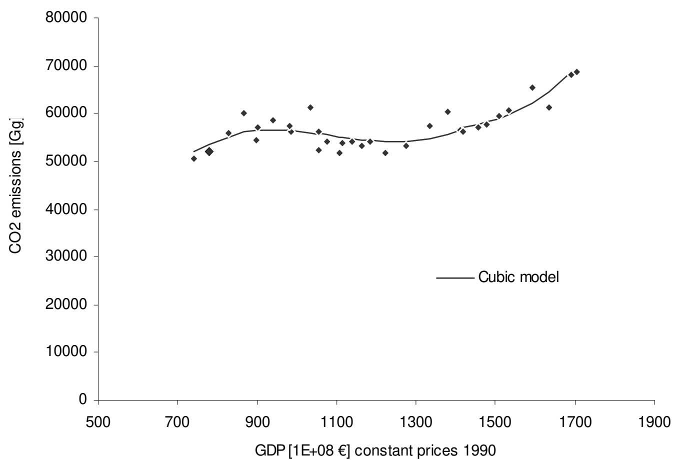

Figure 3.2.4: Fitting of the cubic model for CO_2 emissions and GNP to the data.

To confirm that this conclusions were based on a correct regression using the OLS method, the next table presents the results of the cointegration tests made to the models presented in table 3.2.1.

Explanatory variables	CO_2 and GNP		
	Cubic	Quadratic	Linear
Constant$\times 10^{-4}$	0.462766	1.25679	0.550333
	(0.395731)	(0.933662)	(0.364858)
res_{t-1}	-0.967889^{***}	-0.769076^{**}	-0.616911
	(-5.08405)	(-4.30787)	(-3.12849)
$time \times 10^{-5}$	-0.239563	-0.591117	-0.187446
	(-0.381720)	(-0.814297)	(-0.229103)
Adj. R^2	0.452250	0.364020	0.215364
Schwarz B.I.C.	-197.514	-193.451	-190.187
F-Statistic	12.9719	9.29946	4.97990
Durbin-Watson	2.01688	2.06662	1.95604
n	30	30	30

Table 3.2.2 - Results of the Engel-Granger test for the 3 relevant models. The coefficient associated to res_{t-1} should be tested for significance using the critical values of the Engle-Granger table. Based on the Engle-Granger table: *** - significant at 1%, ** - significant at 5%, * - significant at 10%.

From this table it can be seen that the CO_2 *per capita* emissions is not cointegrated with the *per capita* GNP (linear model), and so the usual methods of regressions (OLS) and testing cannot be applied. On the other hand, the variables in the quadratic and cubic models are indeed cointegrated at 5% and 1% respectively. So, the OLS and the usual tests apply safely to the quadratic and cubic models.

The following table presents the results of the regressions of the general model of equation (2) considering the usual cubic, quadratic and linear relations between CO_2 emissions *per capita* and GDP *per capita*.

The results of the general model are quite unexpected. Most of the explanatory variables came out to be insignificant. The only significant variables are the percentage of services in GDP and the GDP deviation from trend. The Durbin-Watson test for autocorrelation is inconclusive, and the F-test for the overall significance of the model implies the rejection of the null hypothesis of all coefficients being zero.

Altogether, this hints at the possibility of misspecification of the model or omitted variables. These are specially strange results compared to Friedl and Getzner (2003) which estimated the same functional form for CO_2 emissions for Austria for the period 1960-1999. They conclude that the most appropriate model to describe CO_2 emissions in Austria is a general cubic model. The data used here is from the World Bank and from the UNSTAT and Frield and Getzner (2003) use national sources. This is probably the reason why the results are so different.

Explanatory Variables	CO_2 emissions *per capita* 1970-2000		
	Cubic	Quadratic (EKC)	Linear
Constant$\times 10^{-2}$	0.318334	1.5099***	1.4746***
	(0.275635)	(3.48522)	(3.55256)
$y_t \times 10^{-6}$	2.54095	0.221866	0.0947823
	(1.19925)	(0.588966)	(0.644813)
$y_t^2 \times 10^{-9}$	-0.164168	-0.00378956	
	(-1.13549)	(-0.367587)	
$y_t^3 \times 10^{-14}$	0.368137		
	(1.11208)		
$m_t \times 10^{-5}$	-0.349100	3.06088	2.80281
	(-0.072560)	(0.821559)	(0.779619)
$s_t \times 10^{-3}$	-0.160114*	-0.193540*	-0.168246**
	(-1.36465)	(-1.69814)	(-1.88469)
$T_t \times 10^{-4}$	-0.889068	-0.507900	-0.722916
	(-0.793025)	(-0.473486)	(-0.818270)
$yd_t \times 10^{-6}$	0.397293	0.443098*	0.507010**
	(1.29525)	(1.45065)	(2.05475)
Adj. R^2	0.547989	0.543530	0.559322
SSR$\times 10^{-5}$	0.169211	0.178310	0.179314
Schwarz B.I.C.	-201.492	-202.397	-204.027
F-Test	6.19572***	6.95363***	8.61538***
Durbin-Watson	$2.79064^{+/-}$	$2.75128^{+/-}$	$2.71538^{+/-}$
n	31	31	31

Table 3.2.3 - Results of the regressions of the general model for the CO_2 emissions in Austria. In brackets it is presented the value of the t-statistic. *** - significant at 1%, ** - significant at 5%, * significant at 10%.

In the following table it is presented the results of the Engle-Granger test for cointegration of the relations considered in the general model - linear, quadratic and cubic.

Explanatory variables	CO_2 and GNP		
	Cubic	Quadratic	Linear
Constant$\times 10^{-4}$	0.256095	0.637657	0.802470
	(0.285728)	(0.689998)	(0.880873)
res_{t-1}	-2.04045^{***}	-1.95949^{***}	1.96287^{***}
	(-6.51060)	(-6.39981)	(-6.56185)
Δres_{t-1}	0.458241	0.395185	0.399312
	(2.37194)	(2.09419)	(2.16186)
$time \times 10^{-5}$	-0.692366	-0.287736	-0.358179
	(-0.145826)	(-0.589154)	(-0.743992)
Adj. R^2	0.731704	0.725643	0.731842
Schwarz B.I.C.	-199.498	-198.612	-199.054
F-Statistic	26.4541	25.6856	26.4720
Durbin-Watson	1.78544	1.87407	1.91600
n	29	29	29

Table 3.2.4 - Results of the Engel-Granger test for the 3 relevant models. The coefficient associated to res_{t-1} should be tested for significance using the critical values of the Engle-Granger table. Based on the Engle-Granger table: *** - significant at 1%, ** - significant at 5%, * - significant at 10%.

The results of the Engel-Granger test show that the variables in the general models tested are cointegrated at the level of significance of 1%, and hence the OLS and the usual tests of the regressions hold.

Concluding the analysis for Austria, the reduced functional form, of the type of equation (1), that yielded the best results was the cubic model on table 3.2.1. The regressions made using the general model suggest that all the explanatory variables except from those related to GDP are insignificant. Several combinations of the set of explanatory variables were tested and none gave acceptable results (though this could be considered data mining!). The suggestion here is to test for other functional forms for Austria's CO_2 emissions, but this is not carried out here since the objective of this paper is to access the explanatory power of the specific functional form considered and explained in section 2 and it is more interesting to compare the regressions of equation (1) and (2) for other countries.

4.3 Japan

The Japanese economy was included in this analysis for several reasons. First, it is a country which imports a great deal of raw materials, and so it seemed interesting to test the pollution haven hypothesis. Second, it is a highly technologically evolved country and it also seemed interesting for the analysis of the effect of the services sector in the CO_2 emissions. Finally, it was the country which hosted the IPCC Kyoto conference where the Kyoto protocol was signed.

In the figure 3.3.1 the evolution of *per capita* GDP and intensity of CO_2 is presented. The Japanese economy is decoupling the CO_2 emissions from the generation of income. Also, it is assumed that there is no apparent reason for the existence of a structural break in the CO_2 *per capita* emissions. The figure is not conclusive of the existence of a structural break.

Figure 3.3.2 presents the relation of CO_2 emissions with GDP without considering the time. These figure, again, hints at the possibility of a cubic relation between CO_2 emissions with GDP. Finally, in figure 3.3.3 it is presented the evolution of the time series considered in the regressions. In the analysis of the Japanese economy the deviation of the mean temperature is not considered because no data was available. In spite of that, the analysis of Portuguese and Austrian economies showed that these variable was not significant (when compared to the other explanatory variables) to explain the CO_2 *per capita* emissions.

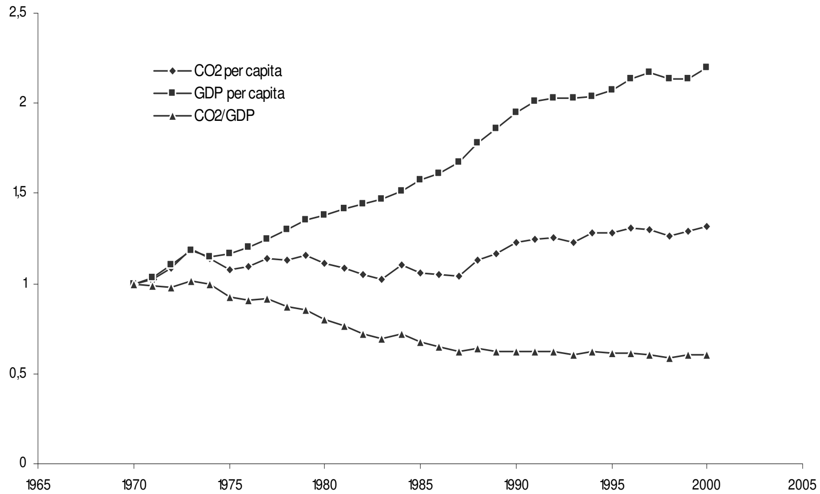

Figure 3.3.1: Evolution of *per capita* CO_2 emissions, GDP and intensity of CO_2 in the GDP (Index 1970=1).

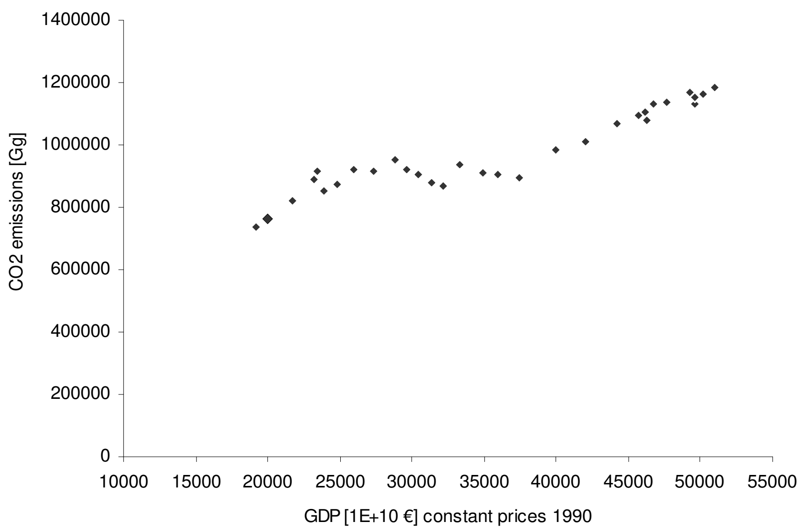

Figure 3.3.2: Relation of CO_2 emissions with GDP.

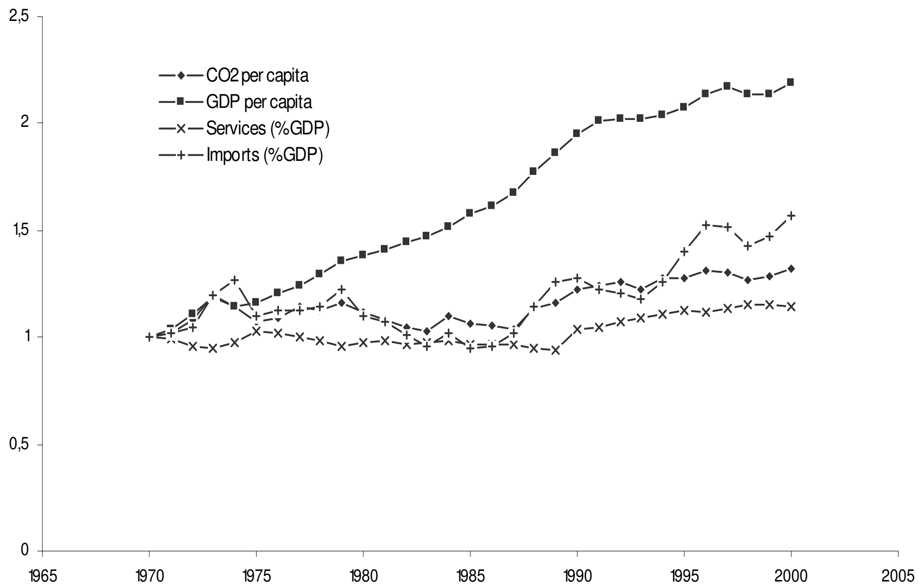

Figure 3.3.3: Relative evolution of the time series considered in the regressions. (Index, 1970=1).

After applying the ADF test for these time series it can be concluded that all the time series used are I(1) at the level of significance of 5%. The following table presents the results of the regressions considering the relation of *per capita* CO_2 emissions with different functional forms of *per capita* GDP as in equation (1).

Explanatory variables	CO_2 emissions *per capita* 1970-2000		
	Cubic	Quadratic (EKC)	Linear
Constant$\times 10^{-2}$	-0.465691	1.1036***	0.588564***
	(-0.739972)	(7.72488)	(18.4577)
$y_t \times 10^{-8}$	1.43000**	-0.288601***	0.0774085***
	(2.10171)	(-2.88251)	(7.43561)
$y_t^2 \times 10^{-14}$	-0.545932**	0.0612644***	
	(-2.28717)	(3.66956)	
$y_t^3 \times 10^{-21}$	0.692726***		
	(2.54905)		
Adj. R^2	0.791931	0.751078	0.644079
SSR$\times 10^{-05}$	0.273763	0.339645	0.502986
Schwarz B.I.C.	-200.902	-199.277	-194.908
F-Statistic	39.0611***	46.2599***	55.2883***
Durbin-Watson	0.899491^+	0.813509^+	0.492086^+
n	31	31	31

Table 3.3.1 - Direct tests of various relations of CO_2 emissions and GNP, including a test of the EKC hypothesis. In brackets it is presented value of the t-statistic. *** - significant at 1%, ** - significant at 5%, * - significant at 10%.

All the models estimated in table 3.3.1 exhibit positive autocorrelation. In this case, the OLS estimator is still linear-unbiased as well as consistent, but it is no longer efficient (i.e., minimum variance). This result may suggest that some relevant variables that were not included in the model should be included. The results of the cointegration test are not presented here but the linear and the quadratic models are not cointegrated, whereas the cubic model is cointegrated at the 10% level.

To see if this is true the following table presents the results of the regressions for the general model.

Explanatory Variables	CO_2 emissions *per capita* 1970-2000		
	Cubic	Quadratic (EKC)	Linear
Constant$\times 10^{-2}$	-1.2834^{***}	-0.493309^{**}	0.327177^{***}
	(-2.60846)	(-1.90756)	(4.68796)
$y_t \times 10^{-8}$	1.44716^{**}	0.353651^{***}	0.0244037^{***}
	(2.42425)	(3.49415)	(3.03916)
$y_t^2 \times 10^{-14}$	-0.466272^{**}	-0.0609237^{***}	
	(-2.12820)	(-3.26053)	
$y_t^3 \times 10^{-21}$	0.488242^{**}		
	(1.85629)		
$m_t \times 10^{-3}$	0.307487^{***}	0.395025^{***}	0.323344^{***}
	(4.72152)	(8.39378)	(6.63786)
$s_t \times 10^{-4}$	0.633987^{***}	0.800126^{***}	0.224156^{*}
	(2.71037)	(3.53355)	(1.35165)
$yd_t \times 10^{-8}$	0.224887^{***}	0.185437^{***}	0.120414^{***}
	(5.42357)	(4.97077)	(3.26255)
Adj. R^2	0.943785	0.938285	0.915425
SSR$\times 10^{-6}$	0.657458	0.751853	1.07157
Schwarz B.I.C.	-217.861	-217.499	-213.724
F-Test	84.9441^{***}	92.2215^{***}	82.1782^{***}
Durbin-Watson	$1.51717^{+/-}$	$1.43418^{+/-}$	$1.12489^{+/-}$
n	31	31	31

Table 3.3.2 - Results of the regressions of the general model for the CO_2 emissions in Austria. In brackets it is presented the value of the t-statistic. *** - significant at 1%, ** - significant at 5%, * significant at 10%.

Although the Durbin-Watson test for autocorrelation is not conclusive the results of table 3.3.2 suggest that incorporating all explanatory variables in the model reduces the autocorrelation observed in table 3.3.1. Before going to the conclusions of this analysis for Japan's economy the following table presents the results for the cointegration tests for the models in the table 3.3.2.

Explanatory variables	General model		
	Cubic	Quadratic	Linear
Constant$\times 10^{-4}$	0.230768	0.260813	0.600245
	(0.366510)	(.395331)	(0.920492)
res_{t-1}	-1.50870^{*}	-1.41984^{*}	-0.639845
	(-4.78749)	(-4.53231)	(-3.99204)
Δres_{t-1}	0.673850	0.626773	
	(2.93669)	(2.82323)	
Δres_{t-2}	0.379667	0.334656	
	(1.91077)	(1.72456)	
$time \times 10^{-5}$	-0.156350	-0.163207	-0.281655
	(-0.47502)	(-0.472550)	(-0.804783)
Adj. R^2	0.472355	0.447299	0.334699
Schwarz B.I.C.	-203.641	-202.761	-215.031
F-Statistic	7.04270	6.46275	8.29464
Durbin-Watson	2.11642	2.20873	1.93224
n	28	28	30

Table 3.3.3 - Results of the Engel-Granger test for the 3 relevant models. The coefficient associated to res_{t-1} should be tested for significance using the critical values of the Engle-Granger table. Based on the Engle-Granger table: *** - significant at 1%, ** - significant at 5%, * - significant at 10%.

From the results for the cointegration tests it can be concluded that the general linear model is not cointegrated (at the level of significance of 10%) and hence the results for the linear model in table 3.3.2 represent a spurious regression. On the other hand, the cubic and quadratic forms of the general model are both cointegrated at the level of significance of 10% and consequently the OLS and the usual tests hold.

For, both, the general cubic and quadratic model, based on equation (2), presented in table 3.3.2, all the explanatory variables are significant at the 5% level of significance. The hypothesis of the pollution haven is rejected, in both models, for the Japanese economy since the sign associated with m_t is positive. This means that, the higher the imports the higher the CO_2 emissions in Japan. Also, the service sector in Japan is responsible for the rising of the CO_2 emissions, as in Portugal. However, the yd_t sign is expected and according the discussion in section 1.2.

The interesting effect of general quadratic model is that it is a generalized EKC, since the sign of the y_t^2 is positive.

The next two figures present the comparison of the real data for CO_2 emissions in Japan with the estimated emissions using the general cubic and quadratic model (EKC).

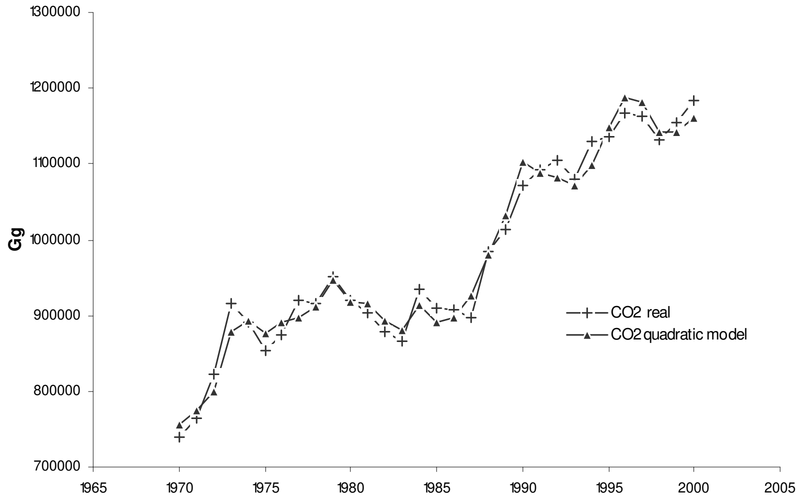

Figure 3.3.4: Comparison of the general quadratic model with the data for CO_2 emissions.

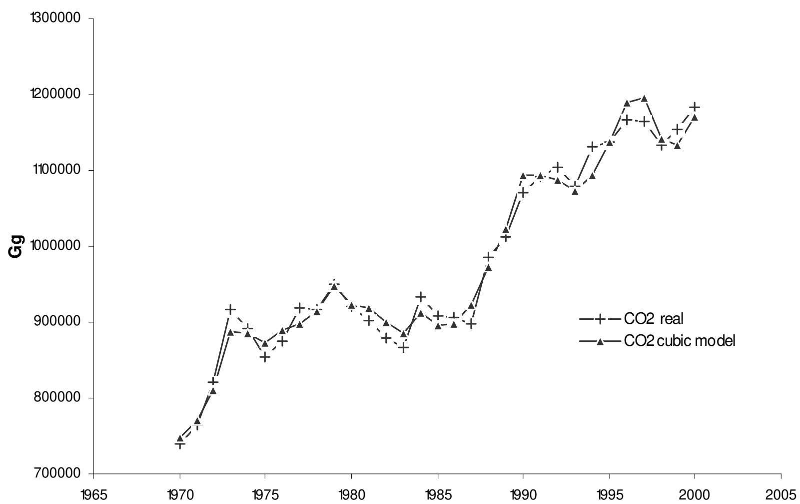

Figure 3.3.5: Comparison of the general cubic model with the data for CO_2 emissions.

Looking at figure 3.3.2 it suggests that Japan exhibits a cubic relation between CO_2 emissions and GDP, however this cannot be safely concluded from the models estimated since the regressions have autocorrelation and the OLS estimator is not efficient. On the other hand, comparing the cointegration test for the general cubic model with the one for the general quadratic model the coefficient of the cubic model is more (though not relevant for the test) significant. Also, comparing the SSR, the Schwarz information criterion and the F-test for the general cubic and quadratic models in table 3.3.2 does not lead to a clear conclusion of what model is the best, econometrically speaking.

Note, however, that the hypothesis of the existence of an EKC for Japan's CO_2 emissions is not rejected.

4.4 USA

The USA is considered in this study for its unquestionable importance on the rest of the world's economies, for being one of the biggest pollutants in the world and for not signing the Kyoto protocol arguing that it was bad for the economy.

In figure 3.4.1, the usual evolution of the intensity of CO_2 in the GDP is presented. The conclusion analyzing this figure is that has for the Japanese economy and with a lower level for the Austrian economy, the growing in income from 1970 until 2000 has being progressively "greened", in the sense that the same amount of income is generated with lower CO_2 emissions. Looking at the time-series for the CO_2 emissions in the USA, there is no clear indication of structural break. Thus, we assume that there is no break point in this time-series and proceed with the usual regressions.

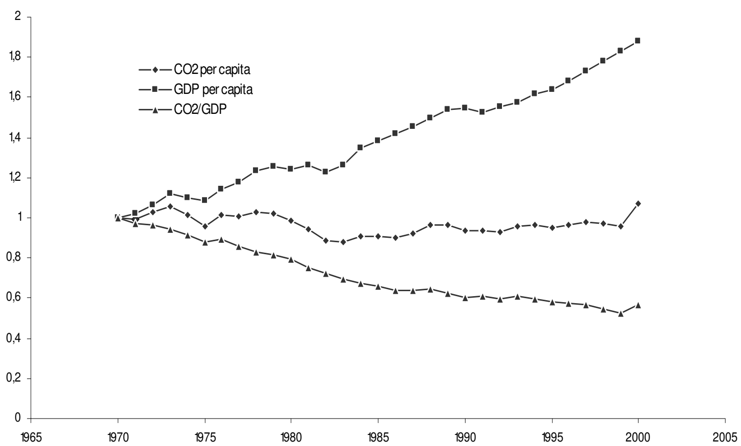

Figure 3.4.1: Evolution of *per capita* CO_2 emissions, GDP and intensity of CO_2 in the GDP (Index 1970=1).

In the figure 3.4.2 presents the relation of CO_2 emissions with GDP for the USA economy. This, as for the case of the Austrian and the Japanese economies, hint at the possibility of this relation to be a cubic relation.

Figure 3.4.3 presents the evolution of the time-series considered in the analysis here. After applying the ADF test for these time-series, the conclusion is that all the time-series are I(1).

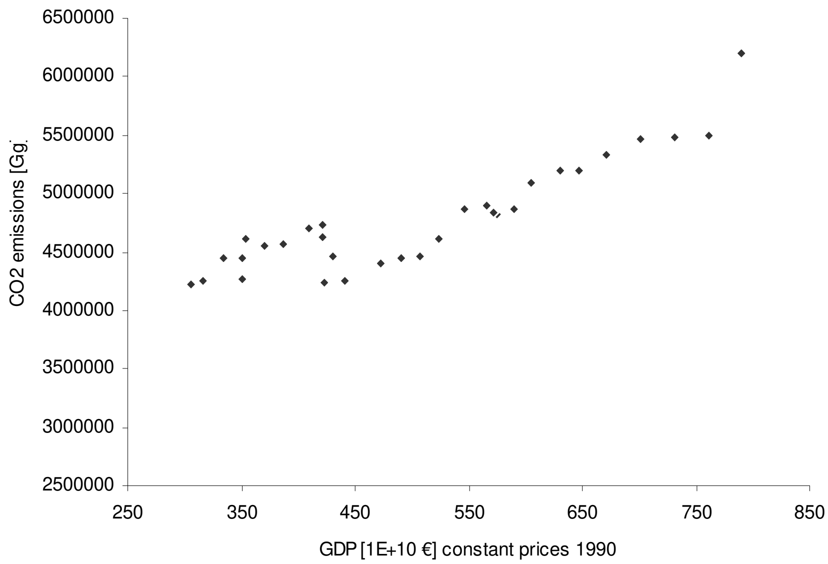

Figure 3.4.2: Relation of CO_2 emissions with GDP.

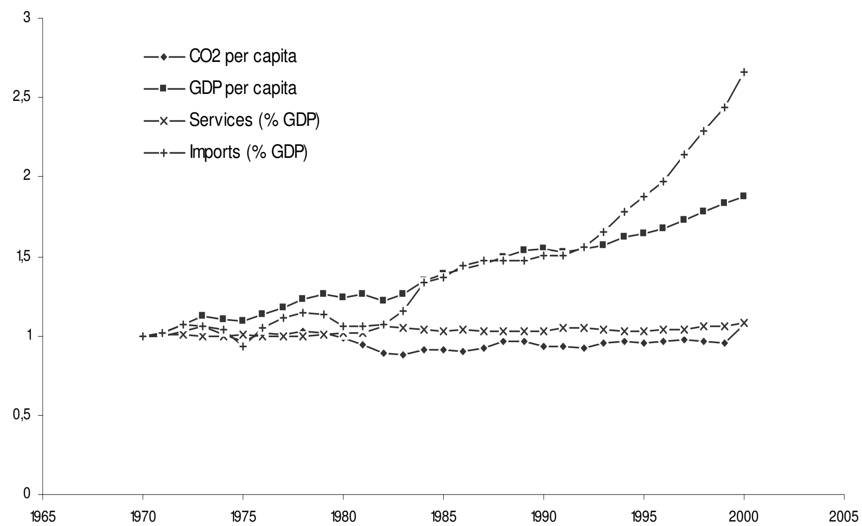

Figure 3.4.3: Relative evolution of the time series considered in the regressions. (Index, 1970=1).

Now, following the same procedure as above, table 3.4.1 presents the results of the regressions of equation (1) type, considering the relation of *per capita* CO_2 emissions with different functional forms of *per capita* GDP.

Explanatory variables	CO_2 emissions *per capita* 1970-2000		
	Cubic	Quadratic (EKC)	Linear
Constant$\times 10^{-2}$	0.016815	0.039736***	0.020913***
	(0.586085)	(8.18061)	(20.9027)
$y_t \times 10^{-7}$	14.5812	−18.8462***	−0.473353
	(0.351364)	(−4.01869)	(−0.997638)
$y_t^2 \times 10^{-10}$	−1.15767	0.434435***	
	(−0.588587)	(3.93121)	
$y_t^3 \times 10^{-14}$	0.247917		
	(0.810761)		
Adj. R^2	0.324259	0.332529	−0.00157296
SSR$\times 10^{-04}$	0.174679	0.178931	0.277691
Schwarz B.I.C.	−172.177	−173.521	−168.425
F-Statistic	5.79857	8.47287***	0.995282
Durbin-Watson	0.905653$^+$	0.938075$^+$	0.544307$^+$
n	31	31	31

Table 3.4.1 - Direct tests of various relations of CO_2 emissions and GNP, including a test of the EKC hypothesis. In brackets it is presented value of the t-statistic. *** - significant at 1%, ** - significant at 5%, * - significant at 10%.

The cubic model based on equation (1) is clearly rejected for the USA since none the variables is significant (at 10%) to explain CO_2 emissions. The quadratic model is not that readily rejected, but the hypothesis of an EKC based on equation (1) for the USA is rejected, since, the coefficient associated with y_t^2 is positive. The linear model is also rejected since, first, the only significant term is the intercept term, and second because the F-test does not reject the null hypothesis of a constant model (all coefficients are zero). All three models exhibit positive autocorrelation, again hinting at the possibility of omitted variables.

Also, analyzing the test for cointegration resulted that the quadratic model is not cointegrated. For that matter, neither the cubic nor the linear models are cointegrated, so the regressions cannot give any safe conclusions.

To see the effects of introducing the rest of the explanatory variables, the following table presents the results of the regressions of the general model.

Explanatory Variables	CO_2 emissions *per capita* 1970-2000		
	Cubic	Quadratic (EKC)	Linear
Constant$\times 10^{-2}$	0.026925*	0.058753***	0.045259***
	(1.47294)	(4.97700)	(5.22233)
$y_t \times 10^{-6}$	4.79830*	−1.29458**	−0.196282**
	(1.67477)	(−1.90005)	(−2.01163)
$y_t^2 \times 10^{-10}$	−2.62985**	0.335096*	
	(−1.91543)	(1.62774)	
$y_t^3 \times 10^{-14}$	0.482262***		
	(2.18091)		
$m_t \times 10^{-4}$	−2.05941	−0.807640	2.86185**
	(−0.851463)	(−0.320502)	(2.46461)
$s_t \times 10^{-3}$	−0.497909***	−0.371849***	−0.346944***
	(−3.70375)	(−2.85659)	(−2.60258)
$yd_t \times 10^{-6}$	0.598331**	0.777746***	0.838228***
	(2.36205)	(3.02684)	(3.19703)
Adj. R^2	0.730968	0.690545	0.670912
SSR$\times 10^{-5}$	0.618174	0.740685	0.819184
Schwarz B.I.C.	−183.126	−182.041	−182.197
F-Test	14.5852***	14.3889***	16.2902***
Durbin-Watson	$1.80965^{+/-}$	$1.49078^{+/-}$	$1.17206^{+/-}$
n	31	31	31

Table 3.4.2 - Results of the regressions of the general model for the CO_2 emissions in Austria. In brackets it is presented the value of the t-statistic. *** - significant at 1%, ** - significant at 5%, * significant at 10%.

Again, incorporating more variables with explanatory power suggests a reduction of the autocorrelation as the results for the Durbin-Watson test hint. However, the Durbin-Watson test yields no conclusive results at 5% significance level. Before trying to make any conclusions of these results the following table presents the results for the cointegratin tests of the models tested in table 3.4.2.

Explanatory variables	General models		
	Cubic	Quadratic	Linear
Constant$\times 10^{-4}$	0.236005	0.786290	0.279860
	(0.125556)	(0.396739)	(0.139319)
res_{t-1}	−0.965018*	−0.840947	−0.613342
	(−4.67053)	(−4.03697)	(−3.08346)
$time \times 10^{-6}$	−1.01159	−3.09585	0.141764
	(−0.099821)	(−0.288806)	(0.013057)
Adj. R^2	0.408611	0.332185	0.210783
Schwarz B.I.C.	−183.359	−181.835	−181.417
F-Statistic	11.0186		
Durbin-Watson	1.86499	1.78024	1.70545
n	30	30	30

Table 3.4.3 - Results of the Engel-Granger test for the 3 relevant models. The coefficient associated to res_{t-1} should be tested for significance using the critical values of the Engle-Granger table.

Based on the Engle-Granger table: *** - significant at 1%, ** - significant at 5%, * - significant at 10%.

The linear and the quadratic models are not cointegrated at the significance level of 10%, hence they are rejected and, on the other hand, the cubic model is cointegrated at the 10% level of significance.

The conclusion is, thus, that the relevant model to describe the CO_2 *per capita* emissions in the USA is the general cubic model presented in table 3.4.2. Interestingly, the coefficient of the service sector is negative meaning that in the USA the services reduces the emissions of CO_2 *per capita.* The estimation of CO_2 emissions using the general cubic model is presented in figure 3.4.4, in comparison with the "real" data.

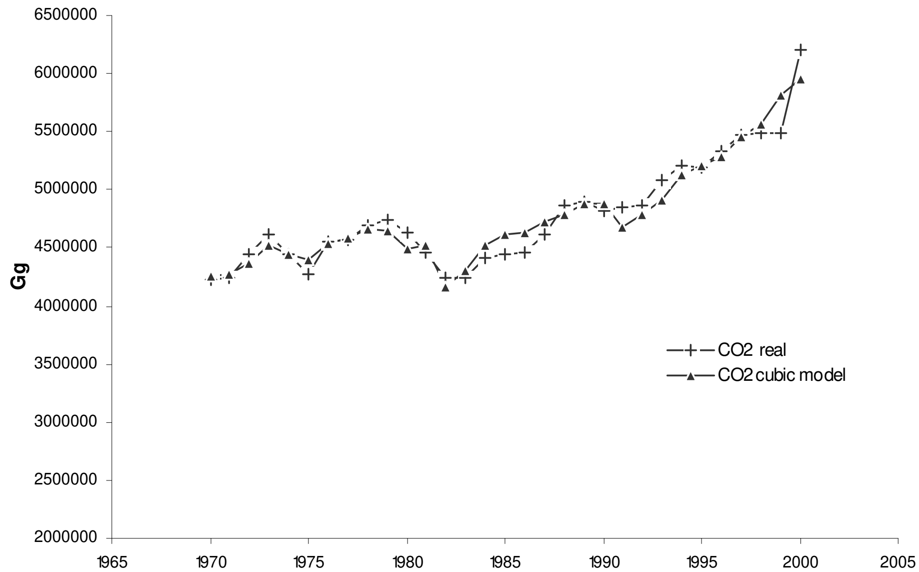

Figure 3.4.4: Comparison of the general cubic model with the data for CO_2 emissions.

4.5 Other countries

The other countries that were analysed to some extend are, Ireland and France. The problem with estimating a EKC for Ireland and also France, is that the time series are integrated of degree zero (specially variables related to the *per capita* GDP) whereas the CO_2 emissions is I(1). This imposes severe problems for the regressions of equation (2) and the models based on equation (1) could not be estimated at all.

5 Summary and conclusions

In this paper four countries for different reasons were analyzed in search for an EKC and for the determinants of *per capita* CO_2 emissions, or a generalized EKC.

The Portuguese results suggest a linear relation between CO_2 emissions and income (measured as GDP). The model that best explains the evolution of the *per capita* emissions of CO_2 is not clear, being the general cubic and the general linear the models that present the best econometric results. In theory, and given the variables that may be considered relevant for the determination of CO_2 emissions the conclusion may lean for the general linear model.

For Austria's case the results suggest a cubic relation between CO_2 emissions and income (measured as GDP). After applying the general models, none of the results is econometrically meaningful and so the recommendation is to test other functional forms or other explanatory variables.

For the Japanese economy, the results suggest a cubic relation between CO_2 emissions and income. Relative to the general models, two models gave econometrically accepted results. One is the general cubic model and the other is a generalized environmental Kuznets curve.

For the USA economy, the though figure 3.4.2 suggest a cubic relation between CO_2 emissions and income, the test based on equation (1) were all rejected. The general model that gave the best results, econometrically speaking, was the general cubic model.

It can be concluded that for CO_2 emissions most of the studies (though few) do not exhibit verify the EKC hypothesis, but exhibit a general cubic model.

The pollution haven hypothesis is rejected for all the countries in the study. Also, the services sector contributes positively for the CO_2 emissions except in the USA where it contributes to lower the CO_2 emissions.

The econometric problems encountered were related to the unit root tests or the degree of integration of the time series, with the cointegration of the relations, and some problems with autocorrelation, probably due to misspecification of the model or omitted variables.

The main relevance of this paper is that the results presented here serve as an awareness for the simplistic way that the results for the EKC are obtained in the literature.

Considering future challenges in this topic, it would be interesting to analyze more countries in this single-country framework; regressions with other functional forms and other explanatory variables are probably required; longer time series are required; and finally, this could be a good framework for the analyze of the effects of aggregation on the estimation of the EKC, in the sense that it may be possible to estimate an EKC using cross-section data, where few countries exhibit an EKC (or extended) when analysed using time series (or it may even be impossible to estimate a EKC for one country only). For this matter, it is presented in figure 4.1 the aggregation of a set of countries analysed here where no EKC was estimated and the aggregation suggests the existence of an EKC.

The research challenge now is to revisit some of the issues addressed earlier in the EKC literature using the rigorous time-series statistics.

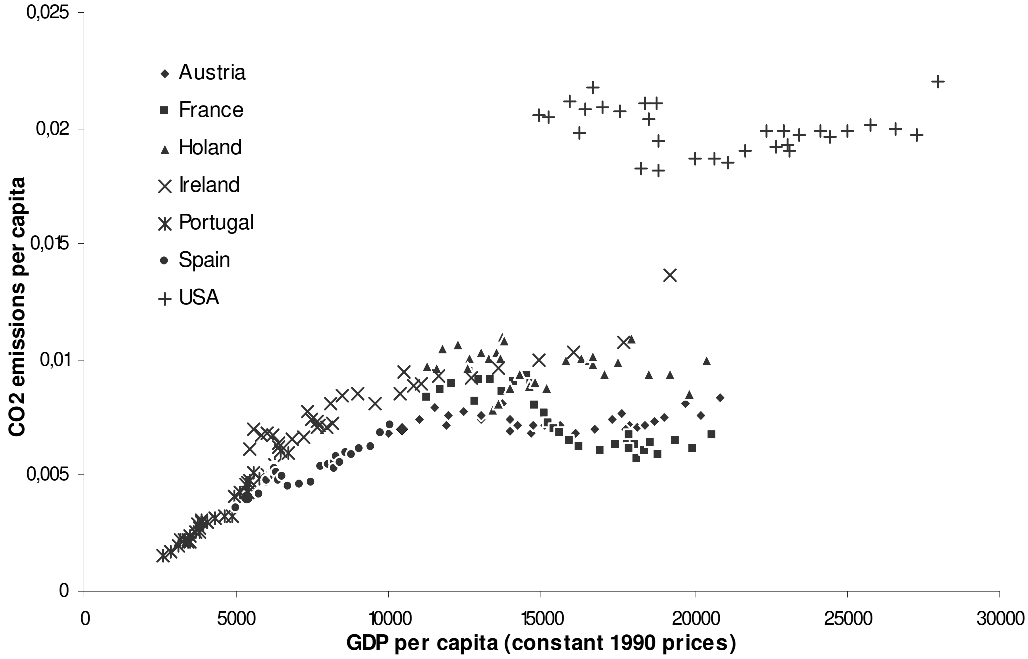

Figure 4.1: Aggregation effect on the estimation of the EKC.

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