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On the Robustness of Robustness Checks of the Environmental Kuznets Curve Hypothesis

by

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Abstract. Since its first inception in the debate on the relationship between environment and growth in 1992, the Environmental Kuznets Curve hypothesis (EKC hereafter) has been subject of continuous and intense scrutiny. The most recent line of investigation criticizes the EKC hypothesis on more fundamental grounds, in that it stresses the lack of sufficient statistical testing of the empirical relationship and questions the very existence of the notion of EKC. Attention is in particular drawn on the stationarity properties of the series involved – per capita emissions or concentrations and per capita GDP – and, in case of presence of unit roots, on the cointegration property that must be present for the EKC to be a well-defined concept. Only at that point can the researcher ask whether the long-run relationship exhibits an inverted-U pattern. On the basis of panel integration and cointegration tests for sulfur, Stern (2002, 2003) and Perman and Stern (1999, 2003) have presented evidence and forcefully stated that the EKC hypothesis does not exist. In this paper we ask whether similar strong conclusions can be arrived at when carrying out tests of system fractional integration and cointegration. As an example we use the controversial case of carbon dioxide emissions. The results show that more EKCs come back into life relative to traditional integration/cointegration tests. However, we confirm that the EKC hypothesis remains a fragile concept.

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On the Robustness of Robustness Checks of the Environmental Kuznets Curve Hypothesis

1. Introduction

The relationship between economic development and environmental quality is the subject of a long-standing debate. About thirty years ago a number of respected scholars, mostly social and physical scientists, attracted the public attention to the growing concern that the economic expansion of the world economy will cause irreparable damage to our planet. In the famous volume *The Limits to Growth* (Meadows, Meadows, Randers, and Behrens, 1972), the members of the Club of Rome ventilated the necessity that, in order to save the environment and even the economic activity from itself, economic growth cease and the world make a transition to a steady-state economy (see Ekins, 2000, for a more thorough discussion of this position).

In the last decade there has prevailed the economists' fundamental view about the relationship between economic growth and environmental quality: an increase in the former does not necessarily mean deterioration of the latter; in current jargon, a de-coupling or de-linking is possible, at least after certain levels of income. This is the basic tenet at the heart of the so-called Environmental Kuznets Curve hypothesis (EKC henceforth), probably the most investigated topic in applied environmental economics.

About a decade ago a spat of initial influential econometric studies (Shafik and Bandyopadhyay, 1992; Grossman and Krueger, 1993, 1995; Panayotou, 1993; Shafik, 1994; Selden and Song, 1994) identified, mostly in the case of local air and water pollutants, a bell-shaped curve for pollution plotted against GDP. This behavior implies that, starting from low per capita income levels, per capita emissions or concentrations tend to increase but at a slower pace. After a certain level of income (which typically differs across pollutants) – the "turning point" – emissions or concentrations start to decline as income further increases. It must be said that in the case of global pollutants like CO_2 the evidence is less clear-cut.

Although many authors rightly warn against the non-structural nature of the relationship, if supported by the data, the inverted-U shape of the curve contains a powerful message: GDP is both the cause and the cure of the environmental problem. However, being based on no firm theoretical basis, the EKC is ill-suited for drawing policy implications. The inverted-U relationship between economic growth and the environment cannot be simply exported to different institutional contexts, to different countries with different degrees of economic development, not even to different pollutants. Particularly in the case of CO_2 emissions extreme caution and careful scrutiny are necessary. Indeed, the global nature of this pollutant and its crucial role as a major determinant of the greenhouse effect attribute to the analysis of the CO_2 emissions-income relationship special interest.

Much has been written on the growth-environment nexus and on the EKC hypothesis. The literature has been mushrooming in the last decade and literature surveys are already numerous. Recent examples include Levinson (2002), Galeotti (2003), and Yandle, Bhattarai, and Vijayaraghavan (2004). These papers all summarize the many empirical contributions to the EKC hypothesis.

Our reading of this literature distinguishes two phases. The first phase can be defined as that of enthusiasm, when the EKC hypothesis is essentially taken for granted, going largely unquestioned. The efforts are concentrated on verifying the shape of the relationship, measuring the income value of the turning point(s), extending the investigation to other pollutants. The second phase witnesses the quest for robustness. The EKC hypothesis is assessed and tested in various directions, including alternative functional forms, different econometric methods, inclusion of additional explanatory variables.

In the last couple of years the EKC has come under a more fundamental attack. One criticism involves the common practice of estimating the EKC on the basis of panel data with the implied homogeneity in the slope/income coefficients across individual units (countries, states, provinces, cities). A second aspect concerns the need to parametrize the EKC relationship prior to estimation. It is clear that any test on the shape of the EKC or any calculation of turning points are all conditional on the specific parametrization chosen. One way to overcome this problem is to use parametrizations as flexible as possible, another one is to use nonparametric or semiparametric regression techniques. A third criticism refers to the stationarity of the variables involved in EKC regressions. If, as in most contributions to the EKC hypothesis, a parametric linear (in parameters) functional form is assumed, this aspect is of crucial importance. According to the theory of integrated time series it is well known that nonstationary series may or may not produce linear combinations that are stationary. If not, all inference on the EKC leads misleading results. Thus, even before assessing the shape or other features of the estimated EKC, the researcher should make sure that pollutant and income, if nonstationary, are cointegrated. It is therefore necessary to run tests of integration and cointegration to guarantee the existence of a well-defined EKC prior to any subsequent step. The evidence of panel integration/cointegration tests – a recent development in the econometrics literature – appears to lead to the conclusion that the EKC is a very fragile concept.

This paper takes up this last and more fundamental difficulty in the current EKC econometric practice. In particular, it is noted that the aforementioned stationarity tests are the standard ones (though in a panel context) where the order of integration of time series is allowed to take on only integer values. So, for instance, a linear combination between pollutant and income gives rise (does not give rise) to a valid EKC only if it is integrated of order zero (one). As a matter of fact, recent progress in econometrics has led to the formulation of the notion and tests of fractional integration and cointegration according to which the order of integration of a series needs not be an integer. The consequence of this fact is that there is a continuum of possibilities for time series to cointegrate – and therefore for the existence of EKCs – thus overcoming the zero-one divide.

In this paper we carry out tests of fractional integration and of fractional cointegration using panel data. We use as an example the case of carbon dioxide for 24 OECD countries over the period 1960-2002. The results show that more EKCs come back into life relative to traditional integration/cointegration tests. However, we confirm that the EKC remains a fragile concept.

The paper is organized as follows. Section 2 is devoted to a brief excursus of the literature. Section 3 carries out "traditional" tests of panel integration/cointegration on our sample of data. Section 4 introduces the reader to system fractional integration and cointegration and shows the results of these tests. In the final section we draw a few conclusions and note that there remain other open questions.

2. A Reading of the Literature

Virtually all EKC studies are concerned with the following questions: (i) is there an inverted-U relationship between income and environmental degradation? (ii) if so, at what income level does environmental degradation start declining? The first wave of contributions to the EKC literature has typically focused upon the answer to these questions. Often out-of-sample projections of pollutant emissions or concentrations have also been a subject of interest.

It is to be noted that both questions have ambiguous answers. The main reason is that, in the absence of a single environmental indicator, the estimated shape of the environment-income relationship and its possible turning point(s) generally depend on the pollutant considered. In general, for indicators of air quality – such as SO_2, NO_x or SPM – there seems to be evidence of an inverted-U pattern. The case of CO_2 is more controversial. So is for deforestation. Furthermore, even when an EKC seems to apply – as in the case of traffic volume and energy use – the turning points are far beyond the observed income range.

More recently, a large, second wave of studies has instead concentrated on the robustness of the previous empirical practice and criticized, from various standpoints, the previous work and findings.[1] The most recurrent criticism is the omission of relevant explanatory variables in the basic relationship. These include: international trade, because of the so-called “pollution haven” or “environmental dumping” hypothesis; energy prices, to account for the intensity of use of raw materials, a host of variables designed to capture political economy considerations due to the public good nature of the environment. In addition, allowance should be made for changes in either the sectoral structure of production or the consumption mix. Finally, a few studies check the robustness of the approach to alternative or more comprehensive datasets.

By and large investigations in this literature are conducted on a panel data set of individual countries around the world. As for the data, those for CO_2 emissions almost invariably have come from a single source, namely the Oak Ridge National Laboratory, while for most of the other pollutants the GEMS data set is employed.[2] The regression model is represented by a static, long-run relationship with a linear or log-linear functional form. Finally, due to the almost complete coverage of world countries, the estimation technique is typically the least square dummy variable method, allowing for both fixed country and time effects.

Particularly the last two aspects of the usual EKC econometric practice have been the subject of further scrutiny in recent contributions. As a first criticism, a few studies have questioned the practice of pooling various countries together (Dijkgraaf and Vollebergh, 1998; Martinez-Zarzoso and Bengochea-Morancho, 2004; Vollebergh, Dijkgraaf, and Melenberg, 2006) with others have carried out EKC investigations on data from individual countries (Vincent, 1997; Egli, 2001).

A second aspect that has attracted attention is the issue of parametrization. Parametric econometric techniques have been the dominating tool for studying the relationship between environment and economic growth. The norm has been given by second order or at most third order polynomial linear or log-linear functions. However, recently a few papers have adopted a nonparametric approach by carrying out kernel regressions (Taskin and Zaim, 2000; Azomahu and Van Phu, 2001; Millimet, List, and Stengos, 2003; Bertinelli and Strobl, 2004; Vollebergh, Dijkgraaf, Melenberg, 2005) or a flexible parametric approach (Schmalensee, Stoker, and Judson, 1998; Dijkgraaf and Vollebergh, 2001; Galeotti and Lanza, 2005; Galeotti, Lanza, and Pauli, 2006).

The most recent line of investigation criticizes the Environmental Kuznets Curve on more fundamental grounds. The attack to the very concept of EKC is brought by Stern in a series of papers (Stern, Common, and Barbier, 1996; Stern, 1998, 2004) where he notes the lack of rigorous statistical testing in much of this literature. Attention is in particular drawn on the stationarity

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[1] Although the critique applies to the whole literature, we will make reference here to studies concerned with a specific pollutant, carbon dioxide. We do so for space reasons and because our empirical application uses CO_2 as a case study.

[2] The data for real per capita GDP are typically drawn from the Penn World Table and are on a PPP basis. Galeotti, Lanza, and Pauli (2006) use instead CO_2 data published by the International Energy Agency.

properties of the series involved – per capita emissions or concentrations and per capita GDP – and, in case of presence of unit roots, on the cointegration property that must be present for the EKC to be a well-defined concept. Only at that point can the researcher ask whether the long-run relationship exhibits an inverted-U pattern. The basic analytical EKC relationship is:

$$y_{it} = \alpha_i + \gamma_t + \beta_1 x_{it} + \beta_2 x_{it}^2 + \beta_3 x_{it}^3 + u_{it} \tag{1}$$

where *y = ln Y* and *x = ln X* and where *Y* is the measure of per capita pollutant, *X* is per capita GDP and *i* and *t* index country (i=1,...,N) and time (t=1,...,T).[3] According to the theory of integrated time series if *y* and *x* in (1) are integrated of order one, i.e. I(1), then their linear combination must be integrated of order zero, i.e. I(0), for the relationship (1) to be statistically and hence economically meaningful. If not, the inference on the EKC produces misleading results. It follows that, even before assessing the shape or other features of the estimated EKC, the researcher should make sure that pollutant and income, if nonstationary, are cointegrated. It is therefore necessary to run tests of integration and cointegration to guarantee the existence of a well-defined EKC prior to any subsequent step. These tests need be extended to a panel environment, a recent development in the econometrics literature.

3. Tests of Panel Integration and Cointegration

A recent development in econometrics extends the by now standard tests of integration and cointegration to use with panel data. Among the most popular panel unit root tests are the statistic proposed by Levin and Lin (1992, 1993) (LL hereafter) and the test by Im, Pesaran, and Shin (2003) (IPS henceforth): see Baltagi and Kao (2000) for a survey.[4]

If the null hypothesis of a unit root in each individual series is not rejected, one can move to verify whether the series are cointegrated or not. This is crucial in order to avoid the spurious regression problem and to conduct valid inference with I(1) variables. The literature on testing for cointegration in a panel context is large (see Breitung and Pesaran, 2005, for an updated survey). Pedroni (1999, 2004) proposes seven cointegration tests which have become very popular among the practitioners. The Pedroni statistics can be divided in two classes, depending on how they deal

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[3] Of course (1) needs not be log-linear, but simply linear in variables.

[4] Other tests have of course been proposed for the same purpose. These include the Levin, Lin and Chu test, Maddala and Wu's ADF Fisher test, the Hadri test, the Breitung test, and others. Because the emphasis here is on the new notion of fractional integration and cointegration we limit our analysis in this section to just two of the most popular panel unit root tests.

with the cross-sectional dimension of the panel. As in the case of panel integration tests, the panel and group-mean cointegration statistics are normally distributed, after appropriate standardization.

On the basis of panel integration and cointegration tests, Stern (2004) and Perman and Stern (1999, 2003) have presented evidence for the case of SO_2 on the basis of which they forcefully state that the EKC does not exist. Looking at CO_2 emissions, similar negative conclusions are arrived at by Müller-Fürstenberger, Wagner, and Müller (2004) and Wagner and Müller-Fürstenberger (2004).

The tests for panel integration and cointegration are by now well understood. A sensible strategy therefore appears to start our empirical investigation by applying those tests to our data as a preliminary step to the developments of the next section. We carry out the LL and IPS tests for panel integration, as well as the seven tests for panel cointegration proposed by Pedroni (1999).[5] All statistics are computed using four different specifications of the test regression, depending on the presence or absence of a linear time trend and/or time dummies. We use annual data on carbon dioxide emissions for twenty-four countries over the period 1960-2002 collected by the International Energy Agency. The other two variables are gross domestic product (GDP) and population. GDP is expressed in billions of PPP 1995 US dollars.[6]

Table 1 shows that each test does not reject the null hypothesis of a unit root in the log of per capita CO_2 for three out of four different specifications of the deterministic components. Turning to per capita GDP we see that the series ln(GDP/POP), $[\ln(GDP/POP)]^2$ and $[\ln(GDP/POP)]^3$ are I(1) for most of the test equations.

A relationship among I(1) variables is not statistically reliable unless they are cointegrated. This implies that the ECK specification (1) has no statistical and economic meaning unless a stationary linear relationship holds among the variables involved. We test for cointegration in our panel using the seven statistics introduced by Pedroni (1999) on the two classical quadratic and cubic formulations of the EKC, which correspond to $\beta_3 = 0$ and $\beta_3 \neq 0$ in model (1). As in the case of panel integration, the cointegration tests are calculated for different specifications of the deterministic components in the cointegrating relationship. The outcome of the tests is reported in Table 2. From a simple inspection of the table, it is clear that the presence of cointegration, and thus the existence of a meaningful ECK, crucially depends on the particular test chosen and the specification of the deterministic components in the test regression (a total of 28 different combinations). Polar cases are represented by the group-mean ρ-statistic, according to which cointegration is never present in the data, and the group-mean *t*-statistic, which always concludes in

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[5] These tests are briefly described in the appendix.

[6] The data are briefly described in the appendix.

favour of cointegration. Overall, the results are mixed, with twelve cases out of twenty-eight (43%) suggesting the existence of a quadratic EKC relationship. The same comments apply to the empirical findings about the presence of a cubic ECK: in this case the results are only slightly more favourable to panel cointegration (thirteen cases out of twenty-eight, i.e. 46%).[7]

4. Tests of System Fractional Integration and Fractional Cointegration

Tough in a panel context, the unit root tests employed in the previous section are the standard ones where the order of integration of a time series is allowed to take on only integer values. Thus, for instance, a linear combination between pollutant and income gives rise (does not give rise) to a valid EKC only if it is integrated of order zero (one). As a matter of fact, recent progress in econometrics has led to the formulation of the notion (and tests) of fractional integration and cointegration, according to which the order of integration of a series or of a linear combination of two or more fractionally integrated series needs not be an integer. Fractional integration (cointegration) can be interpreted as a more sophisticated statistical tool to extract additional information which is crucial to better qualify the non-stationarity (stationarity) properties of a time series (a linear combination of fractionally integrated time series), but cannot be detected within the conventional integration (cointegration) approach. The consequence of this fact is that there is a continuum of possibilities for time series to be integrated and cointegrated – and therefore for the existence of EKCs – thus overcoming the binary outcome of absence-presence of integration and cointegration.

In general we know that a time series z_t is said to be integrated of order d – I(d) – if we have to apply d times the difference operator for $\Delta^d z_t$ to be stationary. That is, $\Delta^d z_t = (1-L)^d z_t$ is I(0), where L is the lag operator ($Lx_t = x_{t-1}$). If we allow d to be any real value, the polynomial in L can be expanded infinitely as:

$$(1-L)^d = 1 - dL - (1/2)d(1-d)L^2 - \ldots - (1/j!)d(1-d)(2-d)\ldots((j-1)-d)L^j - \ldots \qquad (3)$$

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[7] We have also carried out tests of unit roots and of cointegration on the time series of each individual countries. We do not report the results for space reasons. However, it turns out that per capita CO2 is stationary for six countries out of twenty-four (i.e. Denmark, Finland, Greece, Italy, Japan and the Netherlands) whereas per capita GDP is always nonstationary. There cannot be an EKC for those countries. For the others the tests suggest that there is cointegration among the variables involved in both the quadratic and cubic EKCs for three countries out of eighteen (i.e. Portugal, Switzerland and Turkey). On this basis the EKC appears to be a robust concept only for three countries out of twenty-four. Results available upon request.

If d=0 in expression (3), z_t is stationary and possesses "short memory" since its autocorrelations die away very rapidly. If $0<d<1/2$ z_t is still stationary, however its autocorrelations take more time to vanish. When $1/2\leq d<1$ z_t is no longer stationary, but it is still mean reverting, that is shocks to the series tend to disappear in the long-run. Finally, if $d\geq 1$ z_t is nonstationary and non-mean reverting (e.g. Gil-Alana, 2006). Thus, the knowledge of the fractional differencing parameter d is crucial to describe the degree of persistence in any time series, which typically increases with the value of d.

The econometric literature offers different methods to estimate and test the fractional differencing parameter d which are generally complicated to implement even in a single equation context. The first and most popular method has been proposed by Geweke and Porter-Hudak (1983), who use a semiparametric procedure to obtain an estimate of d based on the slope of the spectrum around the zero frequency. Conversely, Sowell (1992) and Beran (1995) maximize the exact likelihood function of an autoregressive fractionally integrated moving-average (ARFIMA) process for z_t using parametric recursive procedures. Robinson (1994) proposes a Lagrange Multiplier-type test of the null hypothesis $d=d_0$, where d_0 is any real value. His test depends on functions of the periodogram and of the spectral density function of the error process for z_t.[8] A more straightforward approach to the estimation and testing of d relies on the fact that expression (3) allows z_t to be represented as an infinitely lengthy autoregressive (AR) polynomial:

$$\left(1-L\right)^d z_t = z_t - \varphi_1 z_{t-1} - \varphi_2 z_{t-2} - .... = u_t \tag{4}$$

where u_t is a classical error process and the parameters φ_j, j=1,2,..., are subject to the restrictions: $\varphi_1=d$, $\varphi_2=(1/2)d(1-d)$, ..., $\varphi_j=(1/j!)d(1-d)(2-d)...((j-1)-d)$, ...[9] It is to be noted that, although always numerically different from zero, the parameters φ_j become very small quite rapidly. This implies that the fractionally differencing parameter d can be estimated from model (4) using nonlinear least squares and a relatively small value of j. The advantage of the nonlinear least squares approach to the estimation and testing of d is that it can be easily extended to the multivariate framework, while the generalizations of univariate frequency domain or exact likelihood methodologies to multivariate analysis are very few, and far from being established in the literature, due to analytical complexities and computational problems.

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[8] See Gil-Alana (2002, 2005) for an extension of the Robinson's test to deal with structural breaks and for a critical evaluation of its performance.

[9] See, among others, Franses (1998, p. 79).

The notion of cointegration has also been recently extended to fractional cointegration: see Cheung and Lai (1993); Baillie and Bollerslev (1994); Jeganathan (1999); Davidson (2002); Caporale and Gil-Alana (2004); Robinson and Iacone (2005). Given a vector of variables Z_t, its components are said to be fractionally cointegrated of order (d, b) if (i) all components of Z_t are $I(d)$ and (ii) there exists a cointegrating vector $\tilde{\beta}$ such that $\tilde{\beta}' Z_t$ is $I(d\text{-}b)$ with $d \geq b$, $b > 0$. In order to test for fractional cointegration a two-step procedure can be used. First, the order of integration for each component of Z_t has to be estimated and its statistical significance tested. Second, if all components of Z_t exhibit a d which is greater than $1/2$, then the residuals from the cointegrating regression can be estimated and their order of integration tested. If the null hypothesis that the order of integration of the residuals d is less than $1/2$ cannot be rejected, then the series are said to be fractionally cointegrated. On the contrary, if this null hypothesis is rejected in favour of $d>1/2$, then the series are not fractionally cointegrated. The values of d and b can be estimated and tested by applying the same approach for fractional integration to the cointegrating residuals. In this context, Krämer (1998) has shown that the popular ADF unit root test is consistent if the order of autoregression of the series does not tend to infinity too fast.

In this section we perform tests for system fractional integration and cointegration, that is we allow the order of integration d_i of a variable z_{it} to take any real value, while in the traditional view d_i is typically limited to be equal to 0, 1 or (rarely) 2. We exploit the panel nature of our data and estimate the fractionally differencing parameter d_i for each variable (namely, the log of per capita CO_2, as well as per capita GDP and its powers), which is observed across different countries and time periods, using a multivariate extension of equation (4). Since the d_i parameters are allowed to vary across individuals, the appropriate estimator is Zellner's nonlinear SUR estimator on the following system extension of model (4):[10]

$$z_{it} = c_i + d_i z_{i,t-1} + (1/2) d_i (1-d_i) z_{i,t-2} + \ldots + (1/j!) d_i (1-d_i)(2-d_i) \ldots ((j-1)-d_i) z_{i,t-j} + \ldots + u_{it} \quad (5)$$

where the country-specific constants, c_i, model potential individual heterogeneity with traditional fixed effects, whereas the variable z_{it} denotes, in turn, the log of per capita emissions, the log of per capita GDP, per capita GDP squared and cube. The value of j in (5), which controls the length of

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[10] As an additional check of our results, we have estimated and tested the differencing parameter d using also the test by Geweke and Porter-Hudak (1983) and the extension proposed by Andrews and Guggenberger (2003). This is based on a bias-reduced (relative to Geweke and Porter-Hudak) log-periodogram regression. We have performed these tests for all variables and countries of our sample. Due to space constraints we do not report them here. The results are qualitatively the same as the ones shown here. The full set of results of both fractional integration and cointegration tests is available from the authors upon request.

the AR approximation (3), is chosen to be equal to eight and corresponds to the minimum number of lags for which the null hypothesis of no residual autocorrelation in the unrestricted version of model (5) is not rejected. Significance of the d_i parameters is evaluated on the basis of robust asymptotic standard errors. Relative to the traditional panel integration and cointegration tests illustrated in Section 3, our procedure has the advantage of taking into explicit account system heterogeneity, since the fractional differencing parameters d_i are allowed to vary across individuals.[11]

Table 3 reports the results of estimating and testing the significance of d_i for each country and the for log of per capita CO_2, as well as per capita GDP and its powers. For GDP and its powers the minimum value of d_i is attained at 0.678 in the case of Japan. This finding implies that the log of per capita GDP and its nonlinear transformations are in general nonstationary, although shocks to these series tend to die away in the long-run. The situation is different when we test the dependent variable for fractional integration. In six countries out of twenty-four (namely, Austria, Finland, Italy, Japan, The Netherlands and Switzerland) the values of d_i are below 0.5, denoting a stationary behaviour of CO_2 emissions. Since the order of system fractional integration of the variables has to be comparable for fractional cointegration to be a meaningful concept, the six aforementioned countries are excluded from the subsequent cointegration analysis.

System fractional cointegration tests are conducted using model (5) where z_{it} is now given by the residuals from the quadratic and cubic EKC specifications. From the empirical findings reported in Table 4 it emerges that both EKC specifications are statistically adequate for seven countries out of eighteen (Australia, Denmark, Ireland, New Zealand, Portugal, Turkey and UK), while Norway supports the cubic EKC relationship only.

The final stage of our empirical analysis is to estimate the parameters of the quadratic and cubic EKC with a system fixed-effect estimator only for those countries which support the presence of system fractional cointegration.[12] The system estimates of the quadratic EKC are illustrated in Table 5. For all countries the slope parameters are statistically significant, with the exception of New Zealand (α and β_1 not significant, β_2 significant at 10%). The table provides also the computation of the so-called "turning points", i.e. the level of income at which CO_2 emissions decline as income further increases. Figure 1 facilitates the interpretation of the estimation results,

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[11] We are currently investigating two econometric aspects related this issue. Firstly, with the help of Monte Carlo simulations we are assessing the robustness of the various tests for fractional integration used here in the attempt to trace the origin of the quantitative differences we have found. Secondly, we are considering the extension to a panel context of tests of fractional integration and fractional cointegration along the lines of the studies in Section 3.

[12] We have performed the usual diagnostic tests (normality, absence of autocorrelation, homoskedasticity) on the residuals of the quadratic and cubic specifications for each country. Since those tests have not pointed out any significant violation of the classical assumptions on the error terms, we have decided not to report them in order to economize space. However, the full set of diagnostic checks is available from the authors upon request.

representing the in-sample as well as the out-of-sample tendency of individual EKCs. Australia, Ireland and Turkey are still on the ascending part of their EKC, with turning points expected to occur at income values which are not included in our sample. Conversely, Denmark has already reached the turning point and is presently at the beginning of the downward sloping part of its EKC, whereas the UK seems to have started the process of reducing per capita CO_2 emissions since the early Eighties. The predictions about New Zealand and Portugal are not informative or problematic, as their EKC is not concave. Estimates of the cubic EKC specification are reported in Table 6, while Figure 2 shows the evolution of individual EKCs. Of eight countries which support the hypothesis of system fractional cointegration, only three suffer from misspecification of the cubic EKC relationship. For Australia, the fixed-effect coefficient α and the slope coefficients β_1, β_2 and β_3 are not statistically significant at conventional levels. Denmark shows that the quadratic and the cubic terms are not statistically relevant, while the log of per capita GDP is significant only at 10%. In the case of Turkey, the only statistically significant coefficient is the individual country effect. Among the remaining countries, Ireland, New Zealand, Norway and Portugal are on the upward sloping part of their individual EKC, see Figure 2. The out-of-sample performance of Ireland and Norway, however, point to a problematic pattern. The case of Ireland, in particular, shows that using a quadratic specification may be quite limiting if not misleading, compare Figures 1 and 2 for this country. Finally, as in the quadratic case, the cubic EKC for UK is suggesting that this country has started the reduction of per capita CO_2 emission quite early, although, in contrast with the predictions of the quadratic EKC, it is now experiencing decreasing rates of per capita CO_2 reductions. Also this case suggests that using a cubic specification can be important.

5. Conclusions and Further Open Issues

In this paper we have investigated once more the Environmental Kuznets Curve. This is probably the most analyzed topic in applied environmental economics. We have started from recent contributions which criticize the current econometric practice allegedly because it lacks sufficient statistical testing. The criticism has centered upon the question as to whether the time series involved in the EKC relationship display a unit root, and if so whether or not they cointegrate. This is a step that is to be taken preliminary to any further investigation. As the answer in those papers is essentially negative, the EKC appears to be a dead concept.

We have questioned the robustness of the standard tests of integration and of cointegration at the basis of that conclusion. To this end, the concepts of system fractional integration and system fractional cointegration suggested in this paper extend the notion of EKC, in that they introduce more flexibility in determining the order of integration of (and the presence of cointegration among) the variables entering the classical specifications of EKC. This can be seen as a way to resurrect the EKC.

We have carried out our econometric investigation using the prototypical EKC regression model for the controversial case of carbon dioxide as an example for twenty-four OECD countries over the period 1960-2002.

The main findings can be summarized as follows. First, traditional panel integration tests do not reject the null hypothesis of a unit root in the log of per capita CO_2, per capita GDP and its second and third powers. These findings are generally independent of the choice of a particular statistic and of a specific model for the deterministic components. Second, the existence of a meaningful ECK crucially depends on the particular panel cointegration test chosen and the specification of the deterministic components in the test regression. Overall, the results are mixed, with 43% (46%) of the cases suggesting the existence of a quadratic (cubic) EKC relationship. Third, system fractional integration estimation and testing show that for per capita GDP and its powers the minimum value of the fractional integration parameter d_i is attained at 0.678 in correspondence of the first power of GDP for Japan. This finding implies that per capita GDP and its nonlinear transformations are in general nonstationary, although shocks to these series tend to die away in the long-run. The situation is different when we test the dependent variable for fractional integration. In 25% of the cases the value of d_i is below 0.5, denoting a stationary behaviour of per capita emissions. Fourth, system fractional cointegration tests suggest that both EKC specifications are statistically adequate for seven countries out of eighteen, while Norway supports the cubic EKC relationship only. Fifth, the fixed-effect system estimates of the quadratic EKC indicate that for all countries the slope parameters are statistically significant, with the exception of New Zealand. Of the eight countries which support the hypothesis of system fractional cointegration, only three suffer from misspecification of the cubic EKC relationship.

To summarize, the existence of a unit root in the log of per capita CO_2 and GDP series, in addition to the absence of a unit root in the linear combination among these variables, are pre-requisites in order for the notion of EKC to be statistically and economically meaningful. Tests of these hypotheses need however not be confined to the limiting set of integer numbers for the order of integration of the series involved. Nonetheless, our empirical analysis has pointed out that the EKC still remains a very fragile concept.

Although this paper represents a contribution in the direction of a more thorough checking of the statistical robustness of the EKC, further theoretical and empirical investigation is clearly needed before any unquestionable conclusion can be drawn on the existence and validity of the EKC. In particular, we point to three are the open issues. First, the robustness of traditional, as well as fractional, system integration and cointegration tests merits additional attention. On the one hand, many popular panel integration tests rely on implausible assumptions on the behaviour of the error terms (e.g. independent and identically distributed) and on the data generating process (e.g. absence of structural breaks), while critical values for the majority of traditional cointegration tests are simulated and hence heavily dependent on the Monte Carlo experimental design. On the other hand, more precise methods for estimating and testing the fractional differencing parameter d_i than the one used in this paper should be extended to a panel framework.[13] Second, many panel integration and cointegration testing procedures impose the unrealistic assumption of cross-sectional independence. Although the system fractional integration and cointegration approaches adopted in this paper have the advantage of taking explicitly into account individual heterogeneity, further investigation should be welcome. Thirdly, the statistical properties of nonlinear transformations of integrated variables are generally unkown (see McAleer, McKenzie and Pesaran, 1994; Kobayashi and McAleer, 1999).[14] That is, if GDP is I(1), it is easy to show that the logarithmic transformation of GDP cannot have a unit root, the same being true for powers of GDP and of log GDP. Moreover, if GDP and POP are both I(1), nothing can be said about the order of integration of per capita GDP. Finally, given the crucial role of the shape of the relationship in the EKC hypothesis, we would ideally need an integrated framework within which the unknown parametric nature of the relationship and the statistical time series properties of the data could be jointly analyzed. But this is a very complex endeavour. Given the typical structure of the EKC specification, the importance of additional research in this area is evident.

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[13] For instance, Davidson (2002) proposes bootstrapped standard errors in multivariate fractional cointegrating models).

[14] See McAleer, McKenzie and Pesaran (1994) and Kobayashi and McAleer (1999). It is worth mentioning here the work of Dittmann and Granger (2002) who show that taking the square of a nonstationary long memory process does not change the size of the long memory parameter. For higher powers than the square of a nonstationary I(d) process the authors could not establish any theoretical results.

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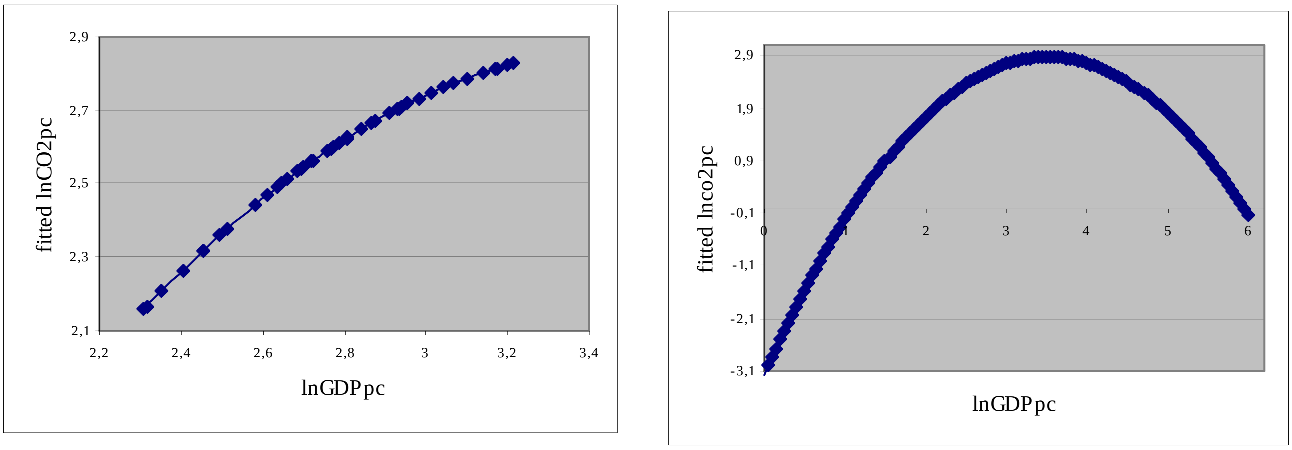
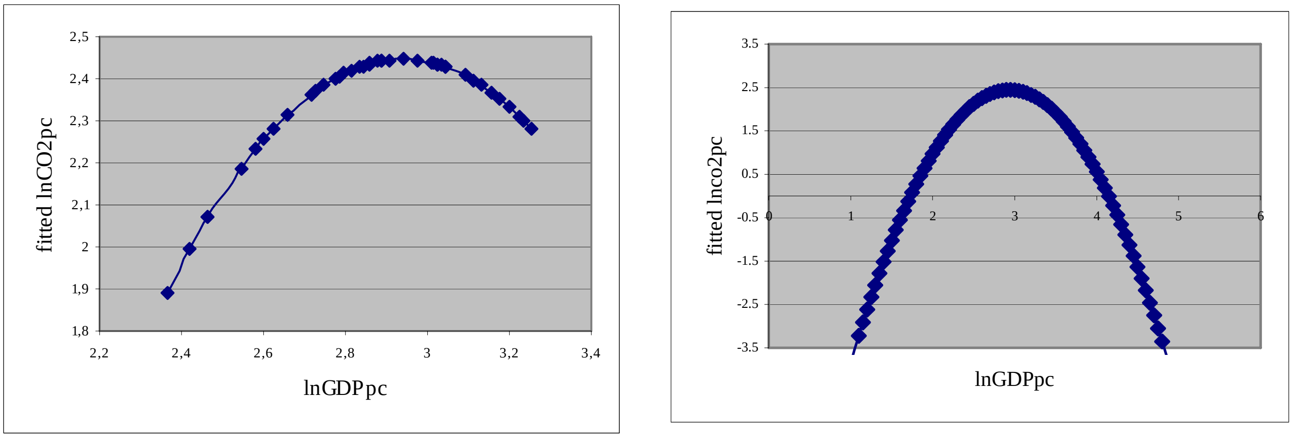
Figure 1. Quadratic EKC – In Sample and out of Sample Tendencies

(a) Australia



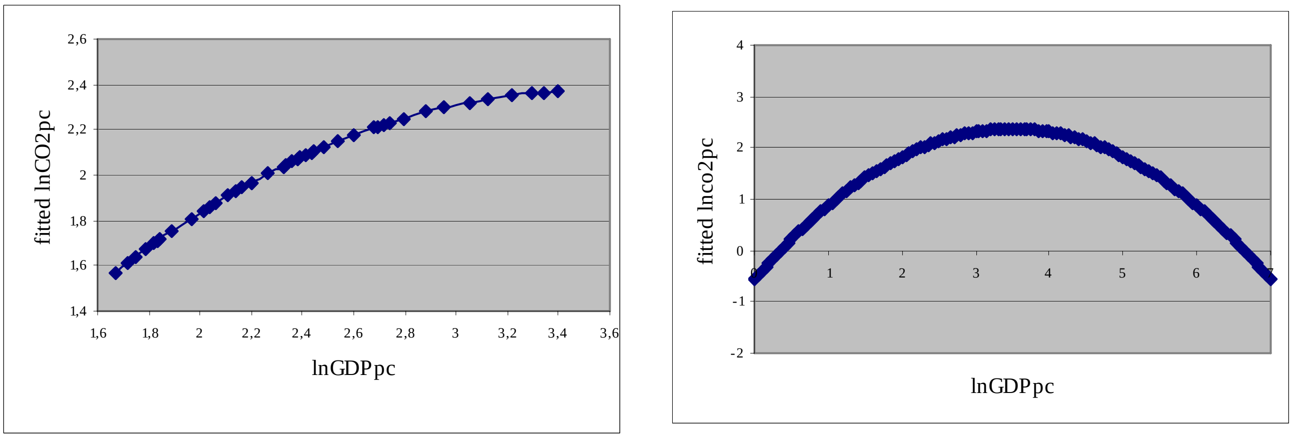
In sample | Out of sample

(b) Denmark



In sample | Out of sample

(c) Ireland

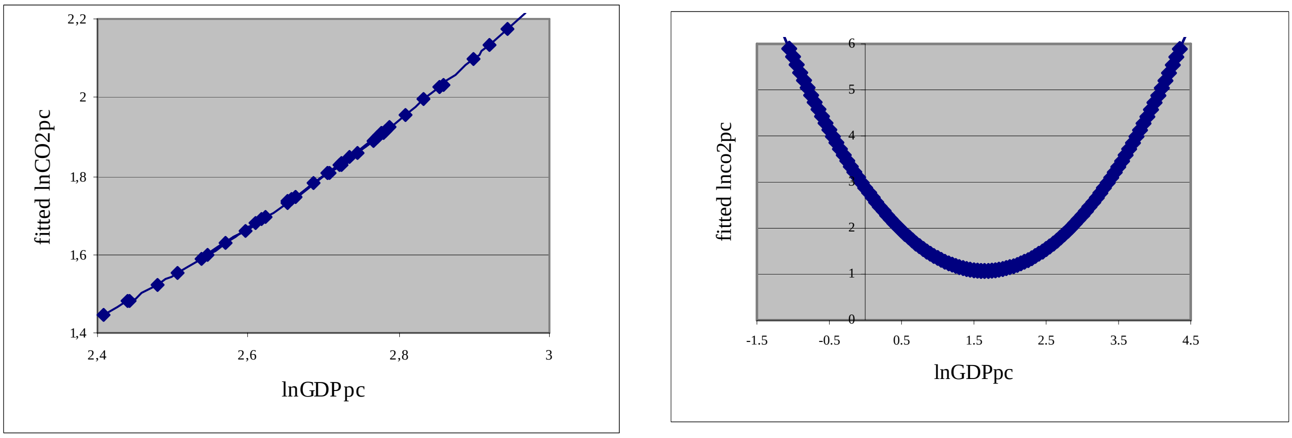


In sample | Out of sample

Notes to Figures 1. The fitted lnCO2pc is the estimated value of ln(CO2/POP) from a given EKC specification, while lnGDPpc=ln(GDP/POP). "In sample" indicates that the values of lnGDPpc reported on the horizontal axis are observed (historical values); "Out of sample" indicates that the estimated EKC curve is plotted against (backward and forward) projected values of lnGDPpc.

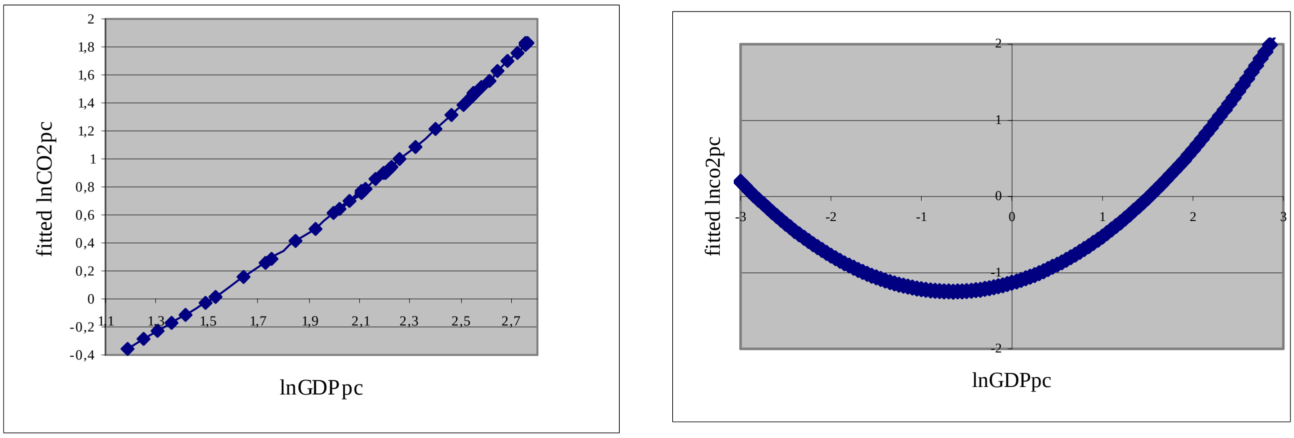
Figure 1 (cont'd)

(d) New Zealand



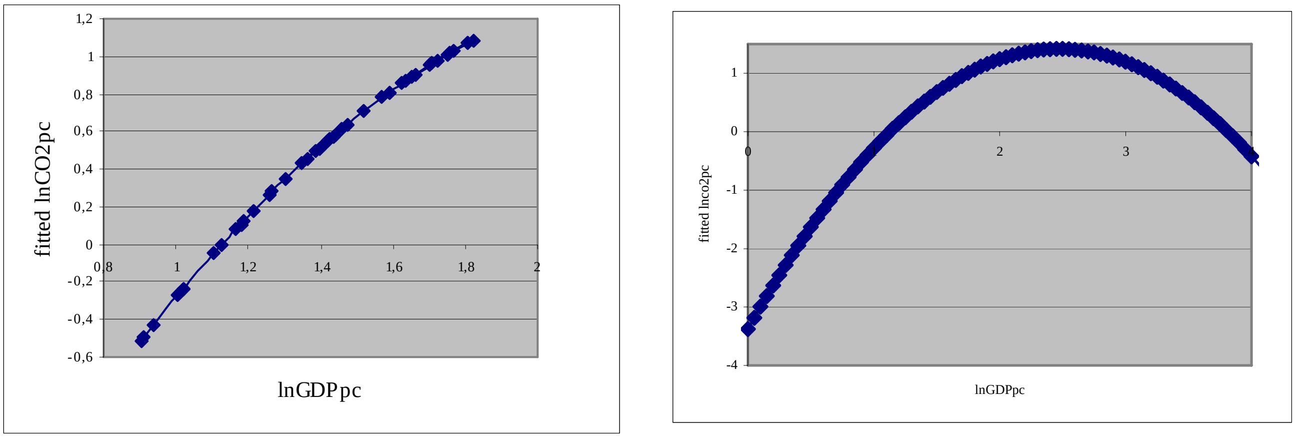
In sample Out of sample

(e) Portugal



In sample Out of sample

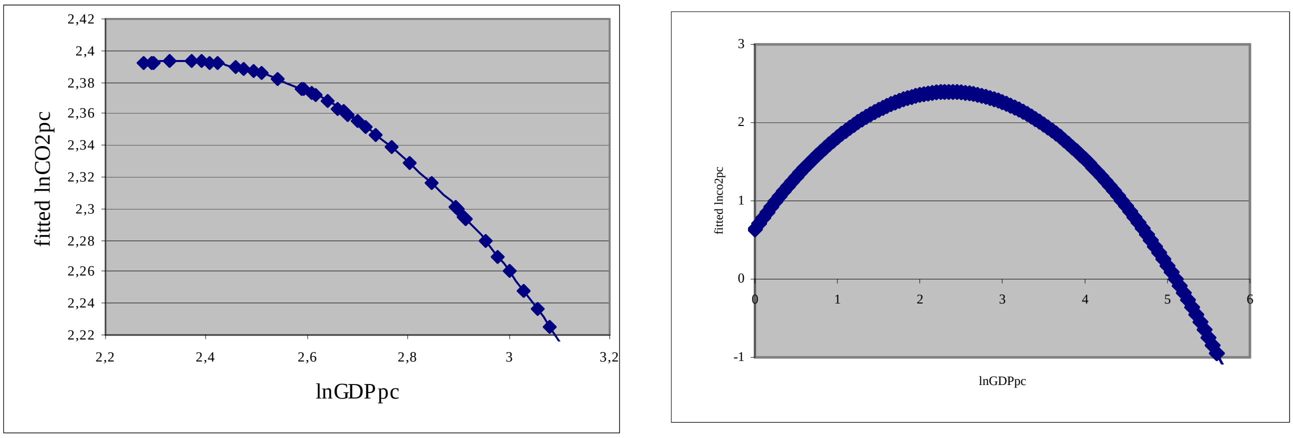
(f) Turkey



In sample Out of sample

Figure 1 (cont'd)

(g) United Kingdom

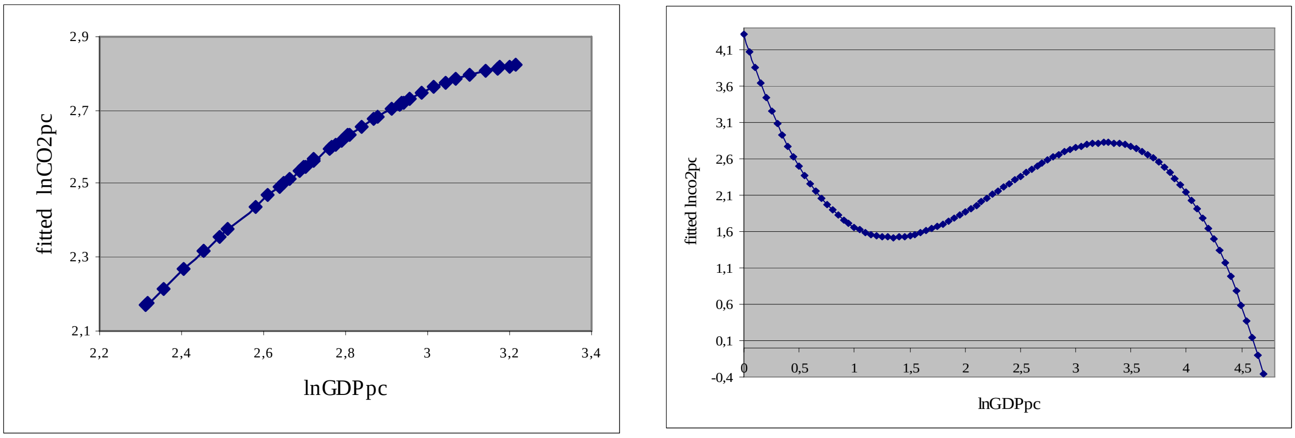


In sample

Out of sample

Figure 2: Cubic EKC – In Sample and out of Sample Tendencies

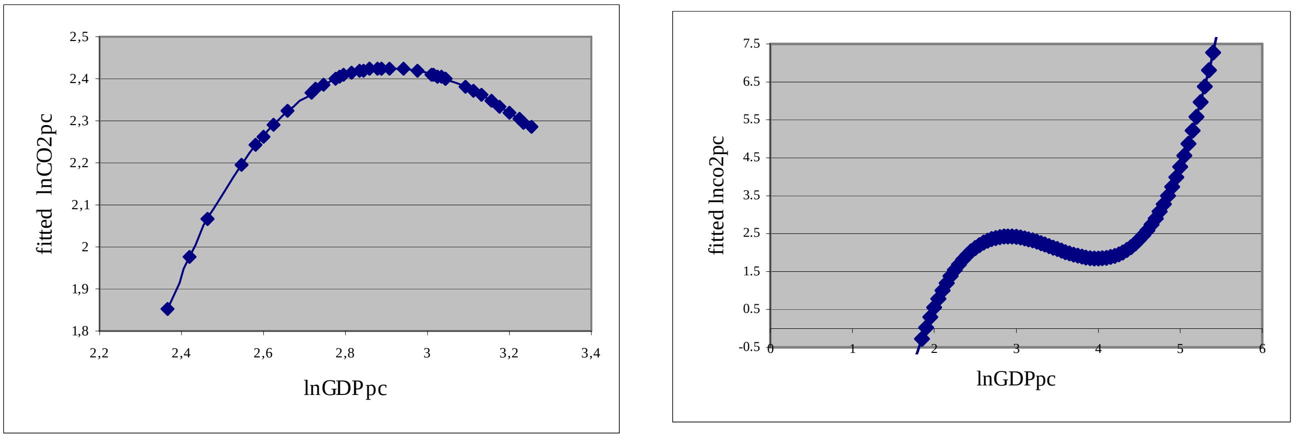
(a) Australia



In sample

Out of sample

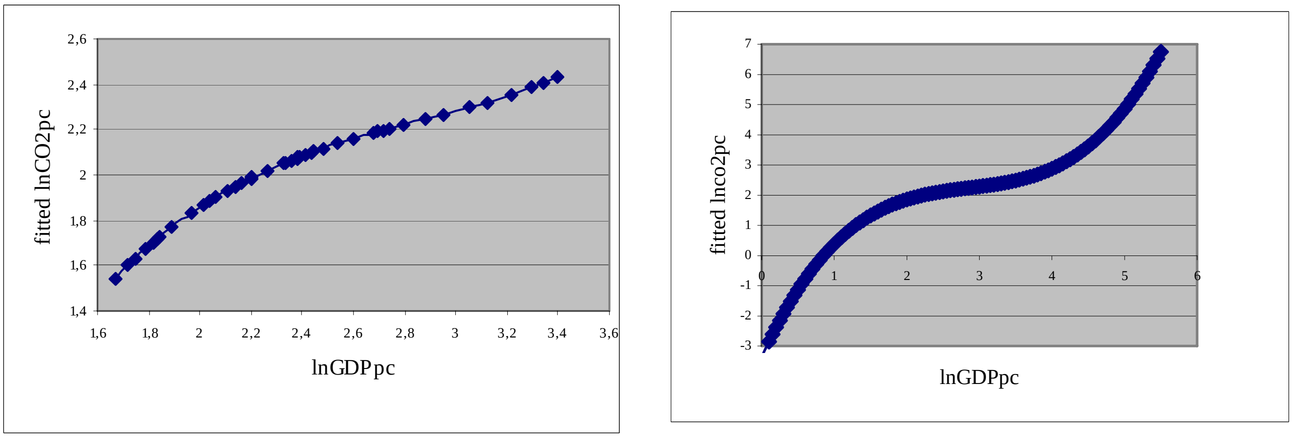
(b) Denmark



In sample

b. Out of sample

(c) Ireland



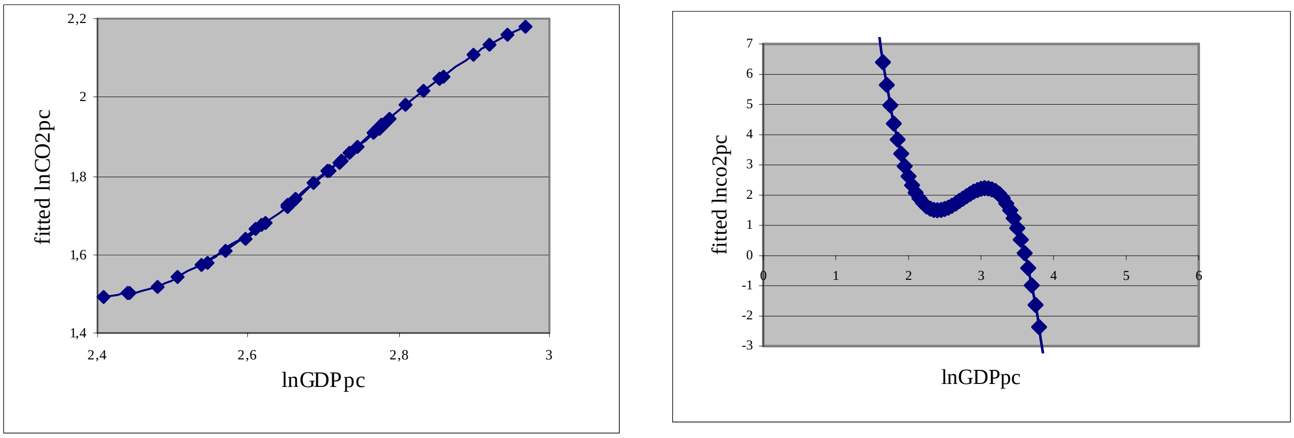
In sample

Out of sample

Notes to Figures 2. See notes to Figure 1.

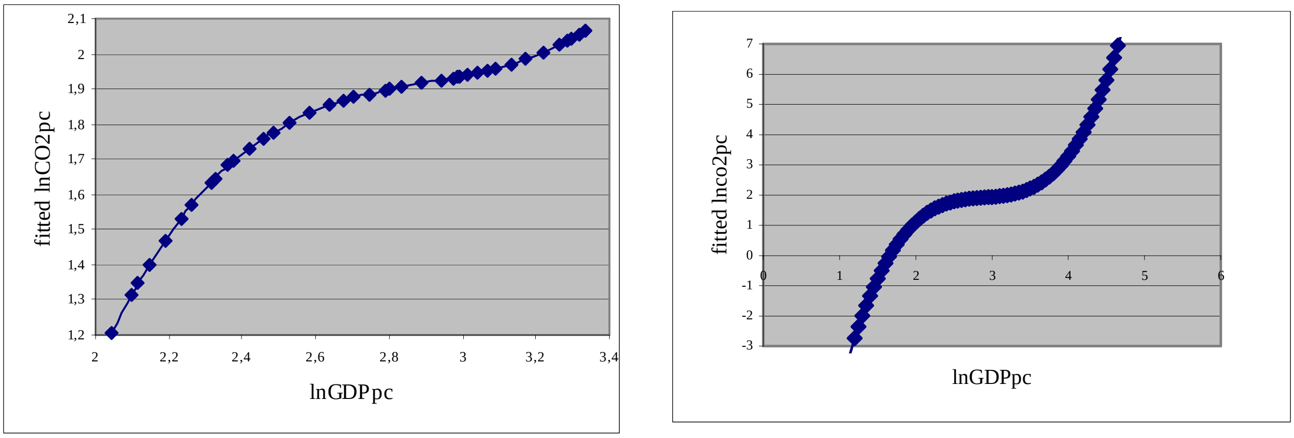
Figure 2 (cont'd)

(d) New Zealand



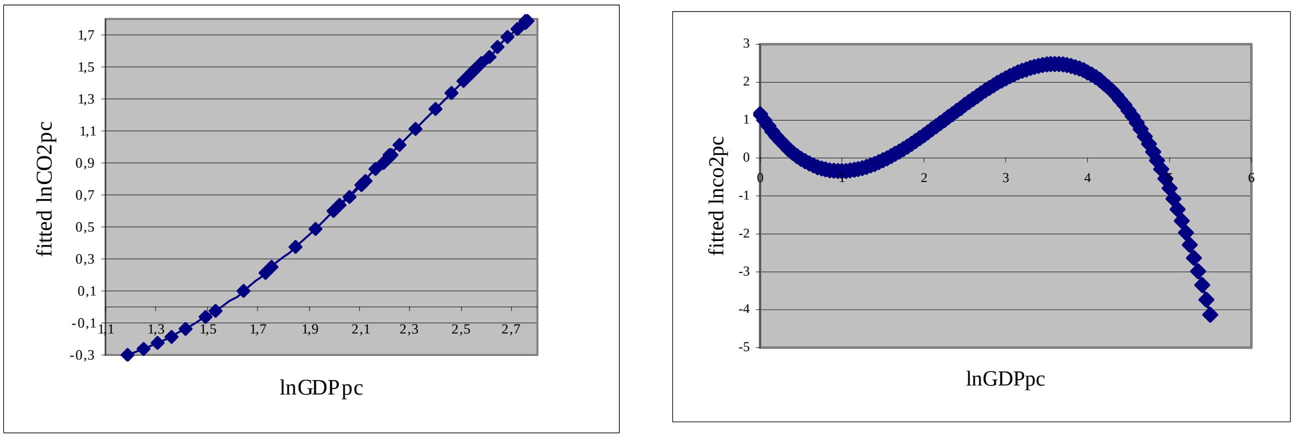
In sample Out of sample

(e) Norway



In sample Out of sample

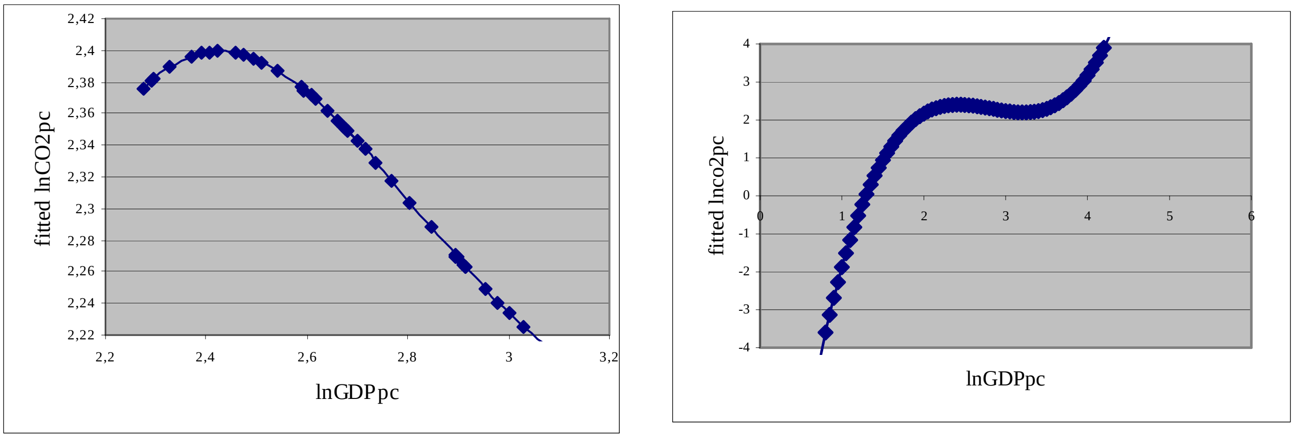
(f) Portugal



In sample Out of sample

Figure 2 (cont'd)

(h) United Kingdom



In sample

Out of sample