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

Marzio Galeotti, Matteo Manera
and Alessandro Lanza

NOTA DI LAVORO 22.2006

**FEBRUARY 2006**

CCMP – Climate Change Modelling and Policy

Marzio Galeotti, *University of Milan and Fondazione Eni Enrico Mattei*
Matteo Manera, *University of Milan-Bicocca and Fondazione Eni Enrico Mattei*
Alessandro Lanza*, Eni S.p.A. and Fondazione Eni Enrico Mattei*

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

**Summary**

Since its first inception in the debate on the relationship between environment and growth in 1992, the Environmental Kuznets Curve has been subject to continuous and intense scrutiny. The literature can be roughly divided in two historical phases. Initially, after the seminal contributions, additional work aimed to extend the investigation to new pollutants and to verify the existence of an inverted-U shape as well as assessing the value of the turning point. The following phase focused instead on the robustness of the empirical relationship, particularly with respect to the omission of relevant explanatory variables other than GDP, alternative datasets, functional forms, and grouping of the countries examined. The most recent line of investigation criticizes the Environmental Kuznets Curve 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 Environmental Kuznets Curve. Attention is drawn in particular on the stationarity properties of the series involved – per capita emissions or concentrations and per capita GDP – and, in case of unit roots, on the cointegration property that must be present for the Environmental Kuznets Curve 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 sulphur, Stern (2002, 2003) and Perman and Stern (1999, 2003) have presented evidence and forcefully stated that the Environmental Kuznets Curve does not exist. In this paper we ask whether similar strong conclusions can be arrived at when carrying out tests of fractional panel 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 remains a fragile concept.

**Keywords:** Environment, Growth, CO2 Emissions, Panel data, Fractional integration, Panel cointegration tests

**JEL Classification:** O13, Q30, Q32, C12, C23

*This paper is part of the research work being carried out by the Climate Change Modelling and Policy Unit at Fondazione Eni Enrico Mattei. We are very grateful to Peter Pedroni for providing us with RATS code and to Luca Meregalli for carrying out and discussing the results of the simulations presented in this paper. This study does not necessarily reflect the views of Eni S.p.A.*

*Address for correspondence*:

Marzio Galeotti
Fondazione Eni Enrico Mattei
Corso Magenta 63
I-20123 Milano
Italy
E-mail: marzio.galeotti@feem.it

## 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 (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 of 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 however 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. The literature has been mushrooming in the last decade and literature surveys are already numerous. Our updated list includes: Stern, Common, and Barbier (1996), Ekins (1997), Stern (1998), Stagl (1999), Panayotou (2000), de Bruyn (2000), Ekins (2000), Borghesi (2001), Dasgupta, Laplante, Wang, and Wheeler (2002), Levinson (2002), Harbaugh, Levinson, and Molloy Wilson (2002), Hill and Magnani (2002), Galeotti (2003), Yandle, Bhattarai, and Vijayaraghavan (2004). These papers all summarize the abundant empirical work done on the EKC.[1]

Our reading of this literature distinguishes two phases. The first phase can be defined as that of enthusiasm, when the notion of EKC is essentially taken for granted, goes 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 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. But the most fundamental criticism refers to the stationarity of the variables involved in EKC regressions. 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

[1] The study of the impact of economic growth on the environment is a significant endeavor, the analysis of feedback effects of the environment on a country well being is even more challenging a task. These considerations help explain why this research field has been explored firstly on empirical grounds and only afterwards with the help of theoretical models.

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 time series and cross-sectional 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 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 Subjective 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 this regard, three main categories of environmental indicators are distinguished: air quality, water quality and other environmental quality indicators. 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. Aside from these cases, studies have found that environmental problems having direct impact on the population – such as access to urban sanitation and clean water – tend to improve steadily with growth. When environmental problems can be externalized (as in the case of municipal solid wastes) the curve does not even fall at high income levels. Finally, 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.[2] The most recurrent criticism is the omission of relevant explanatory variables in the basic relationship. Thus, besides income and time trend, we ought to include trade because of the so-called “pollution haven” or “environmental dumping” hypothesis (Hettige, Lucas, and Wheeler, 1992; Kaufmann, Davidsdottir, Garnham, and Pauly, 1998; Suri and Chapman, 1998), energy prices to account for the intensity of use of raw materials (de Bruyn, van den Bergh, and Opschoor, 1998), and a host of other variables if we care about political economy considerations due to the public good nature of the environment (Torras and Boyce, 1998). In addition, allowance should be made for changes in either the sectoral structure of production or the consumption mix (Rothman, 1998; Hettige, Mani, and Wheeler, 2000). A few studies check the robustness of the approach to alternative or more comprehensive datasets (Harbaugh, Levinson, and Molloy Wilson, 2002; Galeotti and Lanza, 2005).

[2] 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.

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.[3] The functional relationship takes typically either a linear or a log-linear functional form, with a number of studies considering both. 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. A first criticism is that of "income determinism" of empirical EKCs which implicitly hold that the experience of a country is equal to that of all others (Unruh and Moomaw, 1998). Indeed, a few studies have questioned the practice of pooling various countries together and carried out EKC investigations on data from individual countries (Vincent, 1997; Dijkgraaf and Vollebergh, 1998; Egli, 2001). de Bruyn, van den Bergh, and Opschoor (1998) show how a bell shaped EKC may spuriously obtain as a result of the interplay between time effect and aggregation across countries. Martinez-Zarzoso and Bengochea-Morancho (2004) use a pooled mean group estimator that allows for slope heterogeneity in the short run but imposes restrictions in the long run and test their validity.[4] Finally, Vollebergh, Dijkgraaf, and Melenberg (2006) study the complications of overidentifying assumptions like a homogenous cross sectional relationship with specific time and individual effects. They investigate the inference on EKCs when imposing only the assumption of similar time effects between a pair of cross sections.

Parametric econometric techniques have been the dominating tool for studying the relationship between environment and economic growth. They offer a number of well known advantages, although departures from the basic approaches often require the availability of more data on more variables or impose a price in terms of reduced number of degrees of freedom. One aspect that deserves consideration is the issue of the functional form. 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

[3] 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.

[4] This method is also used by Perman and Stern (1999) in the case of $SO_2$.

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 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,...,$T$).[5] 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.

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

## 3. What Do "Traditional" Tests of Panel Integration and Cointegration Say in the Case of $CO_2$ Emissions

As said, the series appearing in the basic EKC regression like (1) may or may not be stationary. If, as in most economic instances, they are I(1) then we must difference them once to make them stationary, or I(0). More generally, a time series $z_t$ is I($d$) if we have to apply $d$ times the difference operator for $\Delta^d z_t$ to be I(0). Augmented Dickey-Fuller type of tests are typically conducted to test the order of integration of a time series. Inference with integrated variables is not valid unless they are cointegrated. Denoting with $Z_t$ a vector of individual I(1) variables, then we say that its components are cointegrated if the linear combination $\hat{\beta}' Z_t$ is I(0) ($\hat{\beta}$ is the cointegrating vector of coefficients estimated with OLS). Augmented Dickey-Fuller type of tests are conducted on the residuals of the OLS regression $\hat{u}_t = \hat{\beta}' Z_t$ (subject to a normalization) to test whether they are I(0) or not.

A recent development in the econometrics literature extends the tests of integration and cointegration to use with panel data. Three are the most popular panel unit root tests: the Levin and Lin (1992, 1993) (LL) statistic, the test by Im, Pesaran, and Shin (2003) (IPS), and a Fisher type statistic (FTT) proposed, among others, by Maddala and Wu (1999). The LL test considers the following regression model:

$$z_{it} = \rho_i z_{i,t-1} + \sum_{j=1}^{p_i} \phi_{ij} \Delta z_{i,t-j} + w_{it}' \gamma + u_{it} \tag{2}$$

where $w_{it}$ represents a vector of deterministic components (e.g. individual effects, time effects, time trend), $\Delta z_{i,t-j}$, $j$=1,…, $p_i$, are the augmentation terms aimed at modelling serial correlation in the error terms and $u_{it}$ is a classical, stationary error process. Under the null hypothesis of a unit root in each series $z_{it}$, $\rho_1 = \rho_2 = ... = \rho_N = \rho = 1$, whereas, under the alternative hypothesis of stationarity of all series $z_{it}$, $\rho_1 = \rho_2 = ... = \rho_N = \rho < 1$. If $\hat{\rho}$ is the OLS estimator of $\rho$ in model (2), LL show that an appropriately standardized ADF statistic of the null hypothesis $\rho$ = 1 has a standard Normal distribution as $T \to \infty$, followed by $N \to \infty$ sequentially. The main drawback of the LL test is that it forces the parameter to be the same across different individuals.

The IPS statistic can be viewed as a generalization of LL, since it allows the heterogeneity of the $\rho_i$ coefficients. Model (2) is estimated with OLS separately for the *i*-th individual and the ADF test for the null hypothesis $\rho_i$ = 1 computed. The IPS test is the average of the individual ADF tests and has a standard Normal distribution as $T \to \infty$ followed by $N \to \infty$ sequentially. Both LL and IPS tests suffer from size distortions when either *N* is small or *N* is large relative to *T* (see Baltagi, 2001, p.239).

Maddala and Wu (1999) propose the Fisher type test $FTT = -2\sum_{i=1}^{N} \ln p_i$, where $p_i$ is the asymptotic p-value associated with the test of a unit root for the *i*-th individual. Since -2ln$p_i$ has a $\chi^2$ distribution with 2 degrees of freedom, FTT has a $\chi^2$ distribution with 2*N* degrees of freedom as $T_i \to \infty$ for finite *N*. Both IPS and FTT tests relax the restriction imposed by the LL statistic that $\rho_i = \rho$ for each individual. Moreover, FTT does not require a balanced panel and it can be applied to any type of unit root test. Conversely, the p-values in the formula for FTT have to be obtained via Monte Carlo simulation.

Once the null hypothesis of a unit root in each individual series is not rejected, it is crucial to verify whether the series are cointegrated or not. 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. In the EKC context these statistics are based on the regression model (1), where the parameters $\beta_i$ are indexed with respect to *i*=1,...,*N* in order to allow for heterogeneity in the cointegrating vector. The null hypothesis for each of the seven tests is the absence of cointegration for each individual. Equivalently, under the null hypothesis the residuals $\hat{u}_{it}$ from *N* separate regressions of the form (1) are I(1) for each individual, that is $\phi_i$=1 in the *i*-th regression: $\hat{u}_{it} = \phi_i \hat{u}_{i,t-1} + \eta_{it}$.

These statistics can be divided in two classes, depending on how they deal with the cross-sectional dimension of the panel. The first class (panel statistics) is based on a pooled estimate of $\phi_i$, whereas the second class (group-mean statistics) uses an average of the different $\phi_i$ estimated separately for each individual. It is clear that the alternative hypotheses for the two classes of tests cannot be identical. For the panel statistics the alternative hypothesis is homogeneous, i.e. $\phi_i = \phi < 1$, while the group-mean statistics are against heterogeneous alternatives. As in the case of panel integration tests, the panel and group-mean 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).

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). 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 p.c. 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 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 test 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

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

group-mean $\rho$-statistic, according to which cointegration is never present in the data, and the group-mean $t$-statistic, which always concludes in 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 Panel Fractional Integration and Fractional Cointegration**

The unit root tests employed in the previous section are the standard ones (though in a panel context) 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 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.

As said, differencing $d$ times an I($d$) time series $z_t$ makes it stationary, i.e. $\Delta^d z_t = (1-L)^d z_t$ 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:

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

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

[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 p.c. CO2 is stationary for six countries out of twenty-four (i.e. Denmark, Finland, Greece, Italy, Japan and the Netherlands) whereas p.c. 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.

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 (see, e.g. Granger, 1980, Hosking, 1981 and 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 parameters $d$, which are generally complicated to implement even in a single equation context. A popular method is 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) estimate the exact maximum likelihood function of an autoregressive (AR), fractionally integrated (FI) moving-average (MA) model for $z_t$ using parametric recursive procedures. Robinson (1994) proposes a Lagrange Multiplier type of 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 $z_t$ (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). A simpler approach to the estimation and testing of $d$ notices that expression (3) allows us to describes $z_t$ as an infinitely lengthy AR polynomial:

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

where $u_t$ is a classical error process and the parameters $\varphi_j$, $j=1,2,...$, are subject to the restrictions: $\varphi_1=d$, $\varphi_2=(1/2)d(1-d)$, ..., $\varphi_j=(1/j!)d(1-d)(2-d)...((j-1)-d)$, ... .[8] Moreover, although they are always numerically different from zero, the parameters $\varphi_j$ become very small quite rapidly. This means that the fractionally differencing parameter $d$ can be estimated from model (4) using nonlinear least squares and a relatively small value of $j$.

The notion of cointegration has been recently extended to fractional cointegration (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 $Z_t$

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

are $I(d)$ and (ii) there exists a cointegrating vector $\tilde{\beta}$ such that $\tilde{\beta}'Z_t$ is $I(d\text{-}b)$ with $b>0$. 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 $Z_t$ have the same order of integration, say $d$, 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 is equal to $d$ cannot be rejected, then the series are not fractionally cointegrated. On the contrary, if this null hypothesis is rejected in favour of a degree of integration which is less than $d$, then the series are fractionally cointegrated. The values of $d$ and $b$ can be estimated and tested by applying the same statistics 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 panel fractional integration and cointegration, that is we allow the order of integration $d_i$ of a generic 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. Estimates of the fractional differencing parameter $d_i$ have been obtained using a nonlinear Seemingly Unrelated Regressions (SUR) estimator on the following panel extension of model (4):

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

where the variable $z_{it}$ denotes in our case p.c. emissions and powers of p.c. GDP. The value of $j$ in (5), which controls the length of 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 carried out 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 panel heterogeneity, since the fractional differencing parameters $d_i$ are allowed to vary across individuals.

Table 3 report the results of estimating and testing the significance of $d_i$ for each country and the 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 panel fractional integration of the variables has to be comparable for fractional cointegration to be a meaningful concept, the six aformentioned countries are excluded from the subsequent cointegration analysis.

Panel 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 panel fixed-effect estimator only for those countries which support the presence of panel fractional cointegration. The panel 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 ($\alpha$ and $\beta_1$ not significant, $\beta_2$ significant at 10%). The table provides also the computation of the so-called "turning points", i.e. the level of income which corresponds to $CO_2$ decline as income further increases. Figure 1 facilitates the interpretation of the estimation results. 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 represents the in-sample as well as the out-of-sample evolutions of individual EKCs. Of eight countries which support the hypothesis of panel fractional cointegration, only three suffer from misspecification of the cubic EKC relationship. For Australia, the fixed-effect coefficient $\alpha$ and the slope coefficients $\beta_1$, $\beta_2$ and $\beta_3$ 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 because allegedly 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 if they cointegrate. This is a step that is to be taken preliminary to any further investigation. Because the answer in this 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 panel fractional integration and cointegration that we have introduced 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 carry out our econometric investigation using the controversial case of carbon dioxide as an example for twenty-four OECD countries over the period 1960-2002.

Our 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, panel 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 ¼ of the cases the value of $d_i$ is below 0.5, denoting a stationary behaviour of per capita emissions. Fourth, panel 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 panel 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 panel 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, nevertheless we believe that further theoretical and empirical investigation is needed before any unquestionable conclusion can be drawn on the existence of EKC. In particular, we point to three are the open issues. First, the robustness of traditional, as well as fractional, panel 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 (for instance, Davidson, 2002, proposes boostrapped standard errors in multivariate fractional cointegrating models). Second, many panel integration and cointegration testing procedures impose the unrealistic assumption of cross-sectional independence. Although the panel fractional integration and cointegration approaches adopted in this paper have the advantage of taking explicitly into account panel heterogeneity, further investigation should be welcome. Finally, the statistical properties of nonlinear transformations of integrated variables are generally unkown (see McAleer, McKenzie and Pesaran, 1994; Kobayashi and McAleer, 1999). 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. Given the typical structure of the EKC specification, the importance of additional research in this area is evident.

## References


Azomahu, T. and N. Van Phu (2001), "Economic Growth and $CO_2$ Emissions: A Nonparametric Approach", BETA Working Paper N.2001-01.

Baillie, R.T. and T. Bollerslev (1994), "Cointegration, Fractional Integratiomn and Exchange Rate Dynamics", *Journal of Finance*, 49, 737-745.

Baltagi, B.H. (2001), Econometric Analysis of Panel Data, second edition, Chichester: Wiley.

Beran, J. (1995), "Maximum Likelihood Estimation of the Differencing Parameter for Invertible Short and Long Memory Autoregressive Integrated Moving Average Models", *Journal of The Royal Statistical Society* B, 57, 654-672.

Bertinelli, L. and E. Strobl (2005), "The Environmental Kuznets Curve Semi-parametrically Revisited", *Economics Letters*, 88, 350-357.

Borghesi, S. (2001), "The Environmental Kuznets Curve: A Critical Survey", in M.Franzini M. and A.Nicita (eds.), Economic Institutions and Environmental Policy, London: Ashgate.

Breitung, J. and M.H. Pesaran (2005), "Unit Roots and Cointegration in Panels", forthcoming in L. Matyas and P. Sevestre (eds.), The Econometrics of Panel Data, third edition, Berlin: Kluwer Academic Publishers.

Caporale, G.M. and L.A. Gil-Alana (2004), "Fractional Cointegration and Real Exchange Rates", *Review of Financial Economics*, 13, 327-340.

Cheung, Y.-W. and K.S. Lai (1993), "A Fractional Cointegration Analysis of Purchasing Power Parity", *Journal of Business and Economic Statistics*, 11, 103-112.

Dasgupta, S., B. Laplante, H. Wang, and D. Wheeler (2002), "Confronting the Environmental Kuznets Curve", *Journal of Economic Perspectives*, 16, 147-168.

Davidson, J. (2002), "A Model of Fractional Cointegration, and Tests for Cointegration Using the Bootstrap", *Journal of Econometrics*, 110, 187-212.

de Bruyn, S.M. (2000), Economic Growth and the Environment, Dordrecht: Kluwer Academic Pub.

de Bruyn, S.M., J.C.J.M. van den Bergh, and J.B. Opschoor (1998), "Economic Growth and Emissions: Reconsidering the Empirical Basis of Environmental Kuznets Curves", *Ecological Economics*, 25, 161-175.

Dijkgraaf, E. and H.R.J. Vollebergh (1998), "Environmental Kuznets Revisited - Time Series Versus Panel Estimation: The $CO_2$ Case", OCFEB Research Memorandum No.9806.

Dijkgraaf, E. and H.R.J. Vollebergh (2001), "A Note on Testing for Environmental Kuznets Curves with Panel Data", Fondazione Eni Enrico Mattei Working Paper N. 63.2001

Egli, H. (2001), "The Environmental Kuznets Curve –Evidence from Time Series Data for Germany", ETH Institute of Economic Research Working paper N.03-28.

Ekins, P. (1997), "The Kuznets Curve for the Environment and Economic Growth: Examining the Evidence", *Environment and Planning* A, 29, 805-830.

Ekins, P. (2000), Economic Growth and Environmental Sustainability, Dodrecht: Kluwer Academic Pub.

Franses, P.H. (1998), Time Series Models for Business and Economic Forecasts, Cambridge: Cambridge University Press.

Galeotti, M. (2003), "Economic Growth and the Quality of the Environment: Taking Stock", Fondazione Eni Enrico Mattei Working Paper N.89.2003.

Galeotti, M. and A. Lanza (2005), "Desperately Seeking (Environmental) Kuznets", *Environmental Modelling and Software*, 20, 1379-1388.

Galeotti, M., A. Lanza, and F. Pauli (2006), "Reassessing the Environmental Kuznets Curve for $CO_2$ Emissions: A Robustness Exercise", *Ecological Economics*, 57, 152-163.

Geweke, J. and S. Porter-Hudak (1983), "The Estimation and Application of Long Memory Time Series Models", *Journal of Time Series Analysis*, 4, 221-238.

Gil-Alana, L.A. (2002), "Structural Breaks and Fractional Integration in the US Output and Unemployment Rate", *Economics Letters*, 77, 79-84.

Gil-Alana, L.A. (2005), "The Test of Robinson (1994) for Fractional Integration. Time Domain versus Frequency Domain", *Mathematical and Computer Modelling*, 42, 235-244.

Gil-Alana, L.A. (2006), "Fractional Integration in Daily Stock Market Indexes", *Review of Financial Economics*, 15, 28-48.

Granger, C. (1980), "Long Memory Relationships and the Aggregation of Dynamic Models", *Journal of Econometrics*, 14, 213-228.

Grossman, G. and A.B. Krueger (1993), "Environmental Impacts of a North American Free Trade Agreement", in P. Garber (ed.), The US-Mexico Free Trade Agreement, Cambridge: MIT Press.

Grossman, G. and A.B. Krueger (1995), "Economic Growth and the Environment", *Quarterly Journal of Economics*, 112, 353-377.

Harbaugh, W.T., A. Levinson, and D. Molloy Wilson (2002), "Reexamining the Empirical Evidence for An Environmental Kuznets Curve", *Review of Economics and Statistics*, 84, 541-551.

Hettige, H., R.E. Lucas, and D. Wheeler (1992), "The Toxic Intensity of Industrial Production: Global Patterns, Trends, and Trade Policy", *American Economic Review Papers and Proceedings*, 82, 473-481.

Hettige, H., M. Mani, and D. Wheeler (2000), "Industrial Pollution in Economic Development: The Environmental Kuznets Curve Revisited", *Journal of Development Economics*, 62, 445-476.

Hill, R.J. and E. Magnani (2002), "An Exploration of the Conceptual and Empirical Basis of the Environmental Kuznets Curve", *Australian Economic Papers*, 41, 239-254.

Hosking, J. (1981), "Fractional Differencing", *Biometrika*, 68, 165-176.

Im, K.S., M.H. Pesaran and Y. Shin (2003), "Testing for Unit Roots in Heterogeneous Panels", *Journal of Econometrics*, 115, 53-74.

Jeganathan, P. (1999), "On Asymptotic Inference in Cointegrated Time Series with Fractionally Integrated Errors", *Econometric Theory*, 15, 583-621.

Kaufmann, R.K., B. Davidsdottir, S. Garnham, and P. Pauly (1998), “The Determinants of Atmospheric $SO_2$ Concentrations: Reconsidering the Environmental Kuznets Curve”, *Ecological Economics*, 25, 209-220.

Kobayashi, M. and M. McAleer (1999), “Tests of Linear and Logarithmic Transformations for Integrated Processes”, *Journal of the American Statistical Association*, 94, 860-868.

Krämer, W. (1998), “Fractional Integration and the Augmented Dickey-Fuller Test”, *Economics Letters*, 61, 269-272.

Levin, A. and C.F. Lin (1992), “Unit Root Test in Panel Data: Asymptotic and Finite Sample Properties”, University of California at San Diego, Discussion Paper No. 92-93.

Levin, A. and C.F. Lin (1993), “Unit Root Test in Panel Data: New Results”, University of California at San Diego, Discussion Paper No. 93-56.

Levinson, A. (2002), “The Ups and Downs of the Environmental Kuznets Curve”, in J.List and A.de Zeeuw (eds.), Recent Advances in Environmental Economics, London: Edward Elgar.

Maddala, G.S. and S. Wu (1999), “A Comparative Study of Unit Root Tests with Panel Data and a New Simple Test”, *Oxford Bulletin of Economics and Statistics*, 61, 631-652.

Martinez-Zarzoso, I. and A. Bengochea-Morancho (2004), “Pooled Mean Group Estimation for an Environmental Kuznets Curve for $CO_2$ ”, *Economics Letters*, 82, 121-126.

Meadows, D.H., D.L. Meadows, J. Randers, and W.W. Behrens (1972), The Limits to Growth, New York: Universe Books.

McAleer, M., C.R. McKenzie and M.H. Pesaran (1994), “Cointegration and Direct Tests of the Rational Expectations Hypothesis”, *Econometric Reviews*, 13, 231-258.

Millimet, D.L., J.A. List, and T. Stengos (2003), “The Environmental Kuznets Curve: Real Progres or Misspecified Models”, *Review of Economics and Statistics*, 85, 1038-1047.

Panayotou, T. (1993), “Empirical Tests and Policy Analysis of Environmental Degradation at Different Stages of Economic Development”, in Technology, Environment, and Employment, Geneva: International Labour Office.

Panayotou, T. (2000), “Economic Growth and the Environment”, CID Working Paper No. 56, forthcoming in K.-G- Mäler and J. Vincent (eds.), Handbook of Environmental Economics, Amsterdam: North-Holland.

Panayotou, T., A. Peterson, and J. Sachs (2000), “Is the Environmental Kuznets Curve Driven by Structural Change? What Extended Time Series May Imply for Developing Countries”, CAER II Discussion Paper No. 80.

Pedroni, P. (1999), “Critical Values for Cointegration Tests in Heterogeneous Panels with Multiple Regressors”, *Oxford Bulletin of Economics and Statistics*, 61, 653-670.

Pedroni, P. (2000), “Fully Modified OLS for Heterogeneous Cointegrated Panels”, *Advances in Econometrics*, 15, 93-130.

Pedroni, P. (2004), “Panel Cointegration: Asymptotic and Finite Sample Properties of Pooled Time Series Tests with an Application to the PPP hypothesis”, *Econometric Theory*, 20, 597-625.

Perman, R. and D.I. Stern (1999), “The Environmental Kuznets Curve: Implications of Non-stationarity”, Centre for Resource and Environmental Studies, Working Papers in Ecological Economics No. 9901.

Perman, R. and D.I. Stern (2003), “Evidence from Panel Unit Root and Cointegration Tests that the Environmental Kuznets Curve Does Not Exist”, *Australian Journal of Agriculture and Resource Economics*, 47, 325-347.

RATS (2004), Reference Manual, version 6, Evanston: Estima.

Robinson, P.M. (1994), “Efficient Tests of Nonstationary Hypotheses”, *Journal of the American Statistical Association*, 89, 1420-1437.

Robinson, P.M. and F. Iacone (2005), “Cointegration in Fractional Systems with Deterministic Trends”, *Journal of Econometrics*, 129, 263-298.

Rothman, D.S. (1998), “Environmental Kuznets Curves – Real Progress or Passing the Buck? A Case for Consumption-Based Approaches”, *Ecological Economics*, 25, 177-194.

Schmalensee, R., T.M. Stoker, and R.A. Judson (1998), “World Carbon Dioxide Emissions: 1950-2050”, *Review of Economics and Statistics*, LXXX, 15-27.

Selden, T.M. and D. Song (1994), “Environmental Quality and Development: Is There a Kuznets Curve for Air Pollution Emissions”, *Journal of Environmental Economics and Management*, 27, 147-162.

Shafik, N. (1994), “Economic Development and Environmental Quality: An Econometric Analysis”, *Oxford Economic Papers*, 46, 757-773.

Shafik, N. and S. Bandyopadhyay (1992), “Economic Growth and Environmental Quality”, Background Paper for the 1992 World Development Report, The World Bank, Washington D.C..

Sowell, F. (1992), “Maximum Likelihood Estimation of Stationary Univariate Fractionally Integrated Time Series Models”, *Journal of Econometrics*, 53, 165-188.

Stagl, S. (1999), “Delinking Economic Growth from Environmental Degradation? A Literature Survey on the Environmental Kuznets Curve Hypothesis”, Working Paper Series of the Research – Focus Growth and Employment in Europe: Sustainability and Competitiveness No. 6.

Stern, D.I. (1998), “Progress on the Environmental Kuznets Curve?”, *Environment and Development Economics*, 3, 173-196.

Stern, D.I. (2004), “The Rise and Fall of the Environmental Kuznets Curve”, *World Development*, 32, 1419-1439.

Stern, D.I., M.S. Common, and E.B. Barbier (1996), “Economic Growth and Environmental Degradation: The Environmental Kuznets Curve and Sustainable Development”, *World Development*, 24, 1151-1160.

Suri, V. and D. Chapman (1998), “Economic Growth, Trade, and Energy: Implications for the Environmental Kuznets Curve”, *Ecological Economics*, 25, 195-208.

Taskin, F. and O. Zaim (2000), “Searching for a Kuznets Curve in Environmental Efficiency Using Kernel Estimation”, *Economics Letters*, 68, 217-223.

Torras, M. and J.K. Boyce (1998), "Income, Inequality, and Pollution: A Reassessment of the Environmental Kuznets Curve", *Ecological Economics*, 25, 147-160.

Unruh, G.C. and W.R. Moomaw (1998), "An Alternative Analysis of apparent EKC-type Transitions", *Ecological Economics*, 25, 221-229.

Vincent, J.R. (1997), "Testing for Environmental Kuznets Curves within a Developing Country", *Environment and Development Economics*, Vol.2, Part 4, 417-432.

Vollebergh, H.R.J., E. Dijkgraaf, and B. Melenberg (2005), "Environmental Kuznets Curves for $CO_2$: Heterogeneity versus Homogeneity", CentER Discussion Paper No.2005-25.

Vollebergh, H.R.J., E. Dijkgraaf, and B. Melenberg (2006), "Identifying Reduced Form Relations with Panel Data: The Case of an EKC for $CO_2$", mimeo.

Wagner, M. and G. Müller-Fürstenberger (2004), "The Carbon Kuznets Curve: A Cloudy Picture Emitted by Bad Econometrics?", University of Bern, Department of Economics Discussion Paper No. 04-18.

Yandle, B., M. Bhattarai, and M. Vijayaraghavan (2004), "Environmental Kuznets Curves: A Review of Findings, Methods, and Policy Implications", PERC Research Study No. 02-1.

## Appendix

As mentioned in the main text, the data generally used in EKC studies concerned with $CO_2$ emissions have been those made available by the Carbon Dioxide Information Analysis Center (CDIAC) of the Oak Ridge National Laboratory. Relative to the CDIAC dataset, those published by the International Energy Agency are based on energy balances and do not include either cement production or gas flaring. However, they appear to be more precise mainly because specific emission coefficients for different energy products are used, while in the CDIAC case a single coefficient is used for gas, oil, and solid fossil fuels without any distinction among individual energy products. Galeotti, Lanza, and Pauli (2006) empirically assess whether or not use of the two datasets has implications for the shape of the estimated EKC. As for the other variables, the series of Gross Domestic Product (GDP) and population of the OECD countries (with the exception of Czech Republic, Hungary, Poland and the Republic of Korea) come from the OECD Main Economic Indicators. The corresponding series for the other countries have been obtained from the World Bank. GDP is expressed in 1995 U.S. dollars on a PPP basis.

**Table 1: Panel Integration – Unit Root Tests**

| Test | Model I | Model II | Model III | Model IV |
|---|---|---|---|---|
| **Per Capita $CO_2$ Emissions** | | | | |
| LL $\rho$-statistic | -0.80583 | 1.78298 | 0.59462 | -3.2925** |
| LL t-$\rho$-statistic | -2.00842* | -1.02564 | 0.43421 | -1.81852 |
| LL ADF-statistic | -0.02421 | -0.19342 | 2.17863* | -1.12808 |
| IPS ADF-statistic | -1.74864 | -0.32272 | 0.79214 | -2.38968* |
| **Per Capita GDP** | | | | |
| LL $\rho$-statistic | 2.00873* | 2.12912* | 0.26864 | 0.16235 |
| LL t-$\rho$-statistic | 0.96456 | -0.54808 | 0.63892 | -0.33855 |
| LL ADF-statistic | 4.8021** | -0.56807 | 0.36504 | -0.82579 |
| IPS ADF-statistic | 6.5250** | -0.56213 | -0.58605 | -1.04530 |
| **Per Capita GDP Square** | | | | |
| LL $\rho$-statistic | 2.7836** | 1.23275 | 1.41423 | 0.87156 |
| LL t-$\rho$-statistic | 2.71262** | -0.17835 | 2.42747* | 0.20555 |
| LL ADF-statistic | 5.1280** | -1.11773 | 1.40783 | -0.63369 |
| IPS ADF-statistic | 6.86365* | -1.70206 | 0.70408 | -1.31288 |
| **Per Capita GDP Cube** | | | | |
| LL $\rho$-statistic | 3.51197** | -0.10296 | 2.15658* | 1.47148 |
| LL t-$\rho$ statistic | 4.32777** | 0.07674 | 3.39633** | 0.59033 |
| LL ADF statistic | 5.79863** | -1.30530 | 1.82047 | -0.77377 |
| IPS ADF statistic | 7.73874** | -1.77127 | 0.85577 | -1.63066 |

Notes to Table 1. (i) Each test is computed using four different model specifications: no trend, no time dummies (Model I); trend, no time dummies (Model II); no trend, time dummies (Model III); iv) trend, time dummies (Model IV). (ii)LL and IPS are the tests proposed by, respectively, Levin and Lin (1992, 1993)and Im, Pesaran and Shin (2003). All test statistics have a standard Normal distribution, after appropriate scaling. (iii) The LL and IPS tests are calculated using the RATS procedure PANCOINT.SRC and RATS (2004). (iv) One (two) asterisk(s) indicates rejection of the null hypothesis of a unit root at the 5% (1%) statistical level.

**Table 2: Panel Cointegration Tests**

| Test | Model I | Model II | Model III | Model IV |
|---|---|---|---|---|
| **Quadratic EKC Specification** | | | | |
| Panel *v*-statistic | 3.07897** | 1.14465 | 0.13798 | 0.75297 |
| Panel $\rho$-statistic | -2.50054* | -0.72121 | -0.68051 | -0.97762 |
| Panel *t*-statistic | -2.92589** | -2.62990** | -1.70974 | -3.11806** |
| Panel ADF-statistic | -1.52018 | -1.00369 | -0.56789 | -2.96972** |
| Group $\rho$-statistic | -1.85558 | -0.22477 | -0.87717 | -0.55732 |
| Group *t*-statistic | -3.14850** | -2.66915** | -2.58476** | -3.50957** |
| Group ADF-statistic | -2.05220* | -1.53475 | -1.13691 | -3.13127** |
| **Cubic EKC Specification** | | | | |
| Panel *v*-statistic | 2.21195* | 1.71434 | 0.62138 | 1.21331 |
| Panel $\rho$-statistic | -1.78383 | -0.96139 | -0.39501 | -1.89025 |
| Panel *t*-statistic | -3.33697** | -3.93661** | -1.58988 | -5.24341** |
| Panel ADF-statistic | -2.13247* | -1.92477 | -0.75376 | -3.89309** |
| Group $\rho$-statistic | -1.31916 | -0.19691 | -0.34388 | -1.05499 |
| Group *t*-statistic | -4.10958** | -4.18910** | -2.24964* | -5.58851** |
| Group ADF-statistic | -3.48292** | -3.32308** | -1.54318 | -5.19425** |

*Notes to Table 2*. (i) Each test is computed using four different model specifications: no trend, no time dummies (Model I); trend, no time dummies (Model II); no trend, time dummies (Model III); iv) trend, time dummies (Model IV). (ii) The panel cointegration tests are proposed by Pedroni (1999). Each statistic has an asymptotic standard Normal distribution, after appropriate standardization. (iii) The LL and IPS tests are calculated using the RATS procedure PANCOINT.SRC and RATS (2004). (iv) One (two) asterisk(s) indicates rejection of the null hypothesis of a unit root at the 5% (1%) statistical level.

**Table 3: Fractional Integration – Estimates of the Differencing Parameter**

| Country | Per Capita $CO_2$ | Per Capita GDP | Per CapitaGDP Square | Per Capita GDP Cube |
|---|---|---|---|---|
| Australia | 0.616 | 1.057 | 1.093 | 1.122 |
| Austria | 0.490 | 0.809 | 0.861 | 0.932 |
| Belgium | 0.886 | 0.823 | 0.873 | 0.936 |
| Canada | 1.116 | 1.275 | 1.196 | 1.197 |
| Denmark | 0.570 | 0.919 | 0.957 | 0.993 |
| Finland | 0.342 | 1.478 | 1.444 | 1.463 |
| France | 1.002 | 0.792 | 0.842 | 0.913 |
| Germany | 1.124 | 0.823 | 0.872 | 0.924 |
| Greece | 0.613 | 0.679 | 1.293 | 1.277 |
| Ireland | 0.703 | 1.381 | 1.488 | 1.591 |
| Italy | 0.369 | 0.779 | 0.838 | 0.902 |
| Japan | 0.356 | 0.678 | 0.767 | 0.843 |
| Luxembourg | 0.972 | 1.062 | 1.127 | 1.177 |
| The Netherlands | 0.339 | 1.606 | 1.545 | 1.503 |
| New Zealand | 0.698 | 0.978 | 1.017 | 1.045 |
| Norway | 0.541 | 0.932 | 1.019 | 1.142 |
| Poland | 1.194 | 1.339 | 1.313 | 1.296 |
| Portugal | 0.763 | 1.423 | 1.399 | 1.378 |
| Spain | 0.645 | 1.671 | 1.659 | 1.658 |
| Sweden | 0.899 | 1.375 | 1.329 | 1.318 |
| Switzerland | 0.141 | 1.319 | 1.271 | 1.264 |
| Turkey | 0.633 | 0.726 | 0.753 | 0.760 |
| UK | 0.698 | 1.055 | 1.099 | 1.147 |
| USA | 1.061 | 0.987 | 1.001 | 1.023 |

*Notes to Table 3*. (i) The figures refer to estimated fractional differencing parameters $d_i$ . Estimates of $d_i$ are obtained using nonlinear SUR on the restricted system of equations:

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

(ii) The panel size is $t$=1,..,43 (annual data from 1960 to 2002) and $N$=1,..,24 (number of OECD countries); $j$ =1,.., 8 is the minimum number of lags for which the null hypothesis of no residual autocorrelation in the following unrestricted system of equations is not rejected: $z_{it} = \varphi_{1i} z_{i,t-1} + \varphi_{2i} z_{i,t-2} + ... + \varphi_{ji} z_{i,t-j} + ... + u_{it}$ .(iii) All estimates are statistically significant at 1%. (iv) All computations have been carried out using RATS (2004).

**Table 4: Fractional Cointegration – Estimates of the Differencing Parameter**

| Country | Quadratic EKC Specification | Cubic EKC Specification |
|---|---|---|
| Australia | 0.296 | 0.287 |
| Belgium | 0.692 | 0.626 |
| Canada | 0.835 | 0.739 |
| Denmark | 0.253 | 0.268 |
| France | 0.780 | 0.742 |
| Germany | 0.543 | 0.550 |
| Greece | 0.920 | 0.818 |
| Ireland | 0.479 | 0.482 |
| Luxembourg | 0.981 | 0.921 |
| New Zealand | 0.296 | 0.251 |
| Norway | 0.589 | 0.270 |
| Poland | 0.919 | 0.957 |
| Portugal | 0.223 | -0.158 |
| Spain | 0.583 | 0.619 |
| Sweden | 0.877 | 0.713 |
| Turkey | -0.121 | -0.074 |
| UK | 0.490 | 0.413 |
| USA | 1.059 | 0.974 |

*Notes to Table 4*. (i) The figures refer to estimated fractional differencing parameters $d_i$ . Estimates of $d_i$ are obtained using nonlinear SUR on the restricted system of equations:

$$\hat{u}_{it} = d_i\hat{u}_{i,t-1} + (1/2)d_i(1-d_i)\hat{u}_{i,t-2} + ... + (1/j!)d_i(1-d_i)(2-d_i)...((j-1)-d_i)\hat{u}_{i,t-j} + ... + \varepsilon_{it}$$

where $\hat{u}_{it}$ are the panel residuals from quadratic and cubic EKC (ii) The panel size is $t$=1,..,43 (annual data from 1960 to 2002) and $N$=1,..,24 (number of OECD countries); $j$ =1,.., 8 is the minimum number of lags for which the null hypothesis of no residual autocorrelation in the following unrestricted system of equations is not rejected: $\hat{u}_{it} = \varphi_1\hat{u}_{i,t-1} + \varphi_2\hat{u}_{i,t-2} + ... + \varphi_j\hat{u}_{i,t-j} + ... + \varepsilon_{it}$ . (iii) All estimates are statistically significant at 1%, with the exception of Portugal (significant at 5%) and Turkey (not significant). (iv) All estimates are statistically significant at 1%. (iv) all computations have been carried out using RATS (2004).

**Table 5: Estimated Quadratic EKC Specification**

| Country | Parameter | | Standard Error | t-statistic | P-value | Turning point | |
|---|---|---|---|---|---|---|---|
| | | | | | | $\ln\frac{GDP}{POP}$ | $\frac{GDP}{POP}$ |
| Australia | $\alpha$ | -3.172 | 0.486 | -6.530 | 0.000 | 3.520 | 33.790 |
| | $\beta_1$ | 3.435 | 0.351 | 9.785 | 0.000 | | |
| | $\beta_2$ | -0.488 | 0.063 | -7.733 | 0.000 | | |
| Denmark | $\alpha$ | -12.020 | 1.439 | -8.348 | 0.000 | 2.938 | 18.876 |
| | $\beta_1$ | 9.845 | 1.019 | 9.654 | 0.000 | | |
| | $\beta_2$ | -1.675 | 0.179 | -9.321 | 0.000 | | |
| Ireland | $\alpha$ | -0.555 | 0.159 | -3.480 | 0.000 | 3.494 | 32.914 |
| | $\beta_1$ | 1.672 | 0.128 | 13.013 | 0.000 | | |
| | $\beta_2$ | -0.239 | 0.025 | -9.474 | 0.000 | | |
| New Zealand | $\alpha$ | 2.874 | 2.602 | 1.104 | 0.269 | - | - |
| | $\beta_1$ | -2.186 | 1.935 | -1.129 | 0.259 | | |
| | $\beta_2$ | 0.662 | 0.359 | 1.842 | 0.066 | | |
| Portugal | $\alpha$ | -1.133 | 0.163 | -6.951 | 0.000 | - | - |
| | $\beta_1$ | 0.347 | 0.165 | 2.098 | 0.036 | | |
| | $\beta_2$ | 0.263 | 0.041 | 6.486 | 0.000 | | |
| Turkey | $\alpha$ | -3.375 | 0.159 | -21.196 | 0.000 | 2.471 | 11.835 |
| | $\beta_1$ | 3,879 | 0.235 | 16.479 | 0.000 | | |
| | $\beta_2$ | -0.785 | 0.085 | -9.264 | 0.000 | | |
| UK | $\alpha$ | 0.638 | 0.524 | 1.218 | 0.224 | 2.350 | 10.483 |
| | $\beta_1$ | 1.492 | 0.387 | 3.856 | 0.000 | | |
| | $\beta_2$ | -0.317 | 0.071 | -4.470 | 0.000 | | |

*Notes to Table 5*. (i) Parameter estimates are obtained with a panel fixed-effect estimator on the following system of quadratic EKC specifications:

$$\ln\left(\frac{CO2}{POP}\right)_{it} = \alpha_i + \beta_{1i}\ln\left(\frac{GDP}{POP}\right)_{it} + \beta_{2i}\left[\ln\left(\frac{GDP}{POP}\right)_{it}\right]^2 + u_{it}$$

(ii) Estimates of the turning points are computed respectively as: $\ln\frac{GDP}{POP} = \frac{\beta_{1i}}{-2\beta_{2i}}$ and: $\frac{GDP}{POP} = e^{\frac{\beta_{1i}}{-2\beta_{2i}}}$. (iii) All computations have been carried out using RATS (2004).

## Table 6: Estimated Quadratic EKC Specification

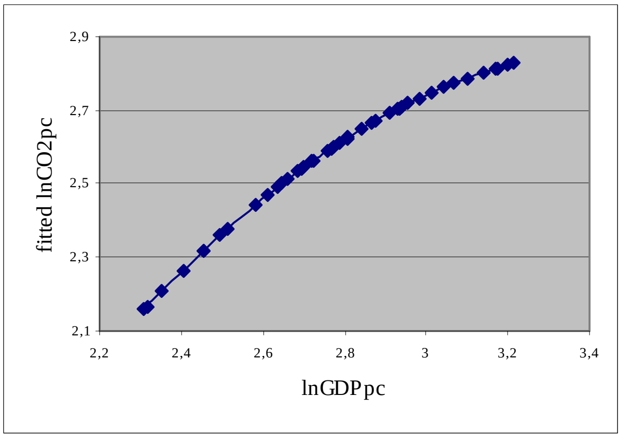
| Country | Parameter | | Standard Error | t-statistic | P-value | Turning point $\ln\frac{GDP}{POP}$ | Turning point $\frac{GDP}{POP}$ |
|---|---|---|---|---|---|---|---|
| Australia | $\alpha$ | 4.311 | 5.339 | 0.807 | 0.419 | min=1.346<br>max=3.276 | min=3.842<br>max=26.870 |
| | $\beta_1$ | -4.803 | 5.841 | -0.822 | 0.411 | | |
| | $\beta_2$ | 2.517 | 2.119 | 1.188 | 0.235 | | |
| | $\beta_3$ | -0.363 | 0.255 | -1.424 | 0.155 | | |
| Denmark | $\alpha$ | -32.141 | 16.401 | -1.959 | 0.050 | max=2.904<br>min=3.990 | max=18.247<br>min=54.055 |
| | $\beta_1$ | 31.42 | 17.566 | 1.789 | 0.074 | | |
| | $\beta_2$ | -9.343 | 6.245 | -1.496 | 0.135 | | |
| | $\beta_3$ | 0.903 | 0.737 | 1.226 | 0.221 | | |
| Ireland | $\alpha$ | -3.364 | 0.811 | -4.147 | 0.000 | - | - |
| | $\beta_1$ | 5.284 | 1.001 | 5.277 | 0.000 | | |
| | $\beta_2$ | -1.743 | 0.404 | -4.318 | 0.000 | | |
| | $\beta_3$ | 0.203 | 0.053 | 3.814 | 0.000 | | |
| New Zealand | $\alpha$ | 98.717 | 42.213 | 2.338 | 0.019 | min=2.402<br>max=3.069 | min=11.045<br>max=21.520 |
| | $\beta_1$ | -109.529 | 47.241 | -2.318 | 0.020 | | |
| | $\beta_2$ | 40.645 | 17.593 | 2.310 | 0.021 | | |
| | $\beta_3$ | -4.953 | 2.180 | -2.272 | 0.023 | | |
| Norway | $\alpha$ | -20.168 | 3.029 | -6.657 | 0.000 | - | - |
| | $\beta_1$ | 22.479 | 3.404 | 6.604 | 0.000 | | |
| | $\beta_2$ | -7.686 | 1.261 | -6.093 | 0.000 | | |
| | $\beta_3$ | 0.883 | 0.154 | 5.726 | 0.000 | | |
| Portugal | $\alpha$ | 1.154 | 0.752 | 1.534 | 0.125 | min=0.984<br>max=3.602 | min=2.675<br>max=36.671 |
| | $\beta_1$ | -3.351 | 1.191 | -2.812 | 0.005 | | |
| | $\beta_2$ | 2.167 | 0.607 | 3.570 | 0.000 | | |
| | $\beta_3$ | -0.315 | 0.100 | -3.146 | 0.001 | | |
| Turkey | $\alpha$ | -2.645 | 0.832 | -3.178 | 0.001 | max=2.151 | max=8.593 |
| | $\beta_1$ | 2.197 | 1.895 | 1.159 | 0.247 | | |
| | $\beta_2$ | 0.470 | 1.406 | 0.334 | 0.738 | | |
| | $\beta_3$ | -0.304 | 0.340 | -0.894 | 0.371 | | |
| UK | $\alpha$ | -14.758 | 4.914 | -3.003 | 0.003 | max=2.423<br>min=3.216 | max=11.280<br>min=24.928 |
| | $\beta_1$ | 18.912 | 5.466 | 3.460 | 0.001 | | |
| | $\beta_2$ | -6.843 | 2.019 | -3.389 | 0.001 | | |
| | $\beta_3$ | 0.809 | 0.247 | 3.269 | 0.001 | | |

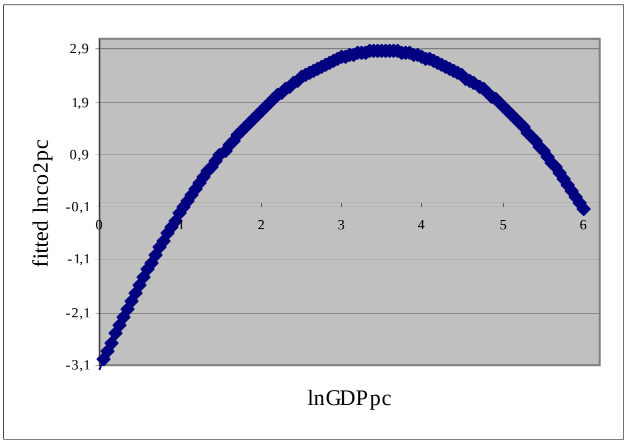
*Notes to Table 6*. See previous table. Parameter estimates are obtained with a panel fixed-effect estimator on the following system of quadratic EKC specifications:

$$\ln\left(\frac{CO2}{POP}\right)_{it} = \alpha_i + \beta_{1i}\ln\left(\frac{GDP}{POP}\right)_{it} + \beta_{2i}\left[\ln\left(\frac{GDP}{POP}\right)_{it}\right]^2 + \beta_{3i}\left[\ln\left(\frac{GDP}{POP}\right)_{it}\right]^3 + u_{it}$$

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

(a) Australia

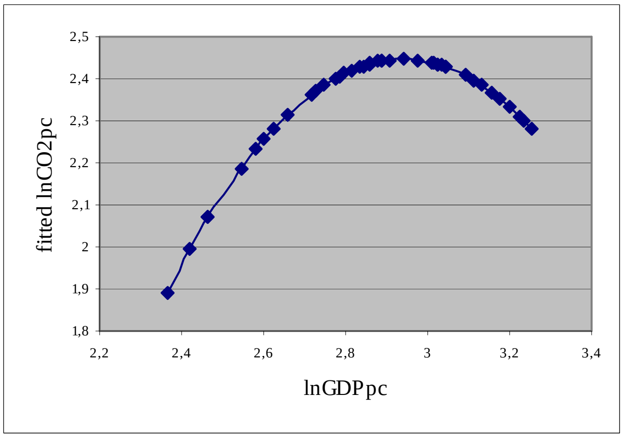


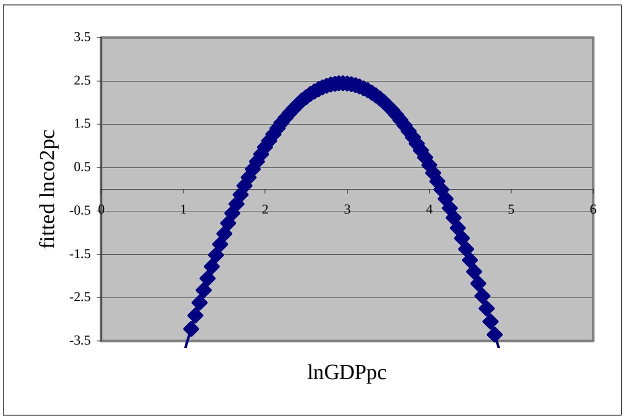




In sample

Out of sample

(b) Denmark

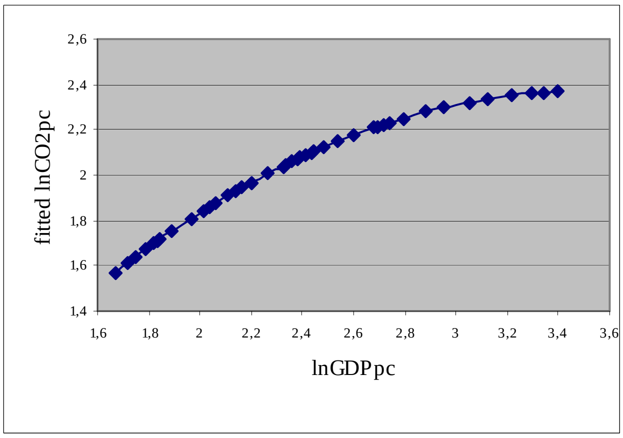


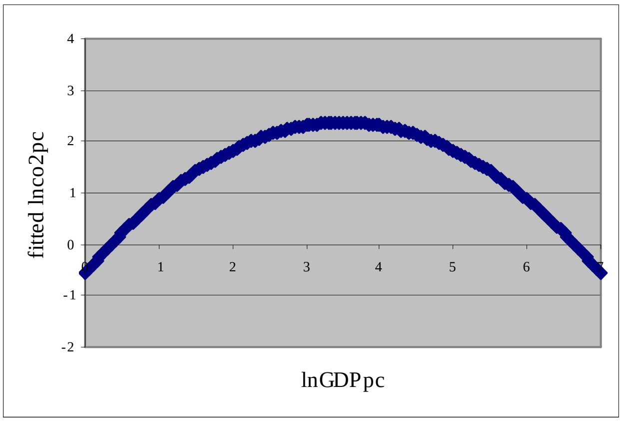




In sample

Out of sample

(c) Ireland



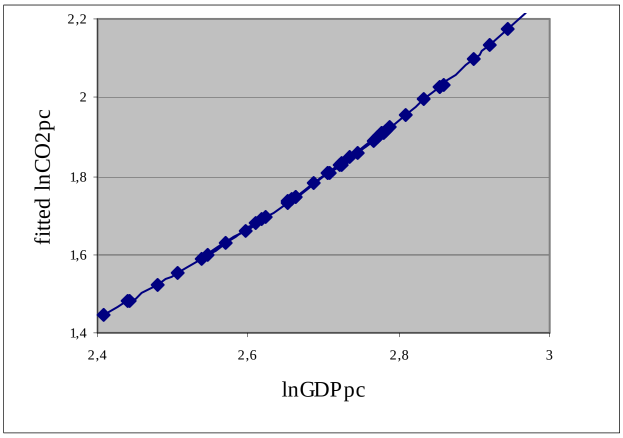

In sample

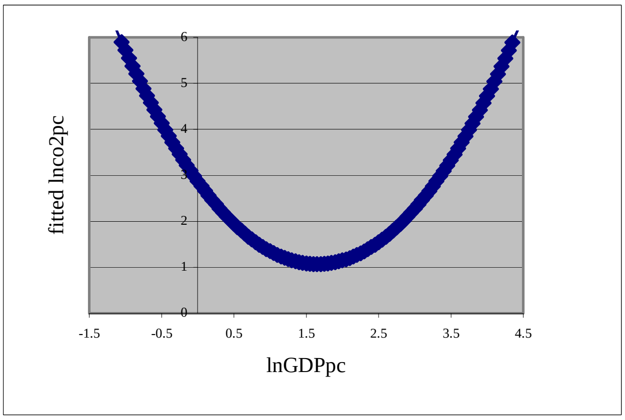
Out of sample

<u>Notes to Figures 1</u>. 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; "Out of sample" indicates that the estimated EKC curve is plotted against values of lnGDPpc which are observed only partially.

**Figure 1** (cont'd)

(d) New Zealand

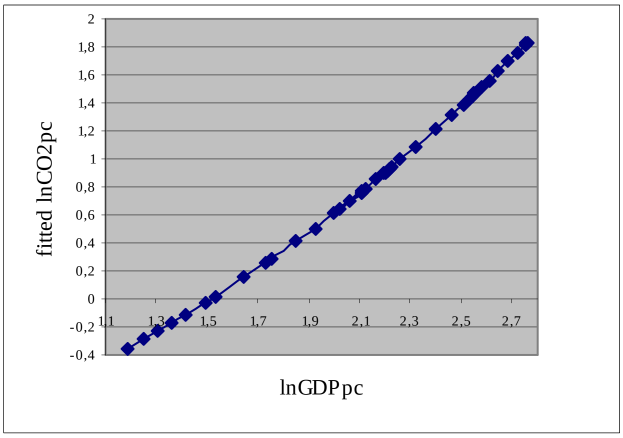


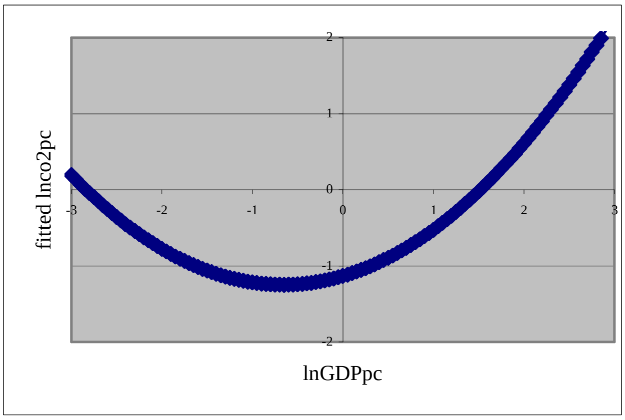




In sample

Out of sample

(e) Portugal

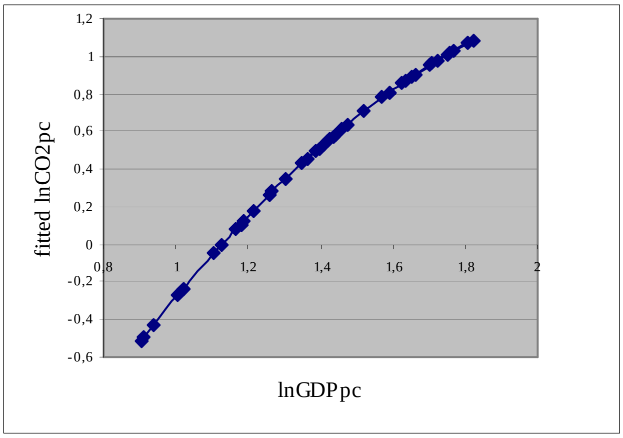


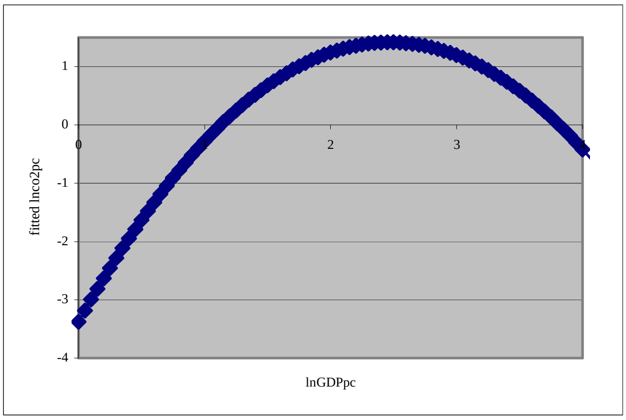




In sample

Out of sample

(f) Turkey



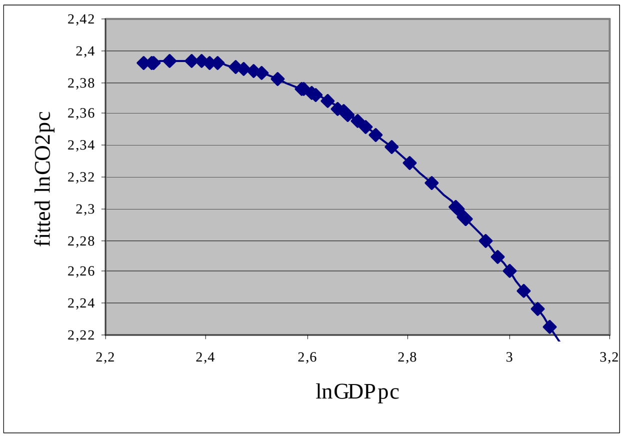




In sample

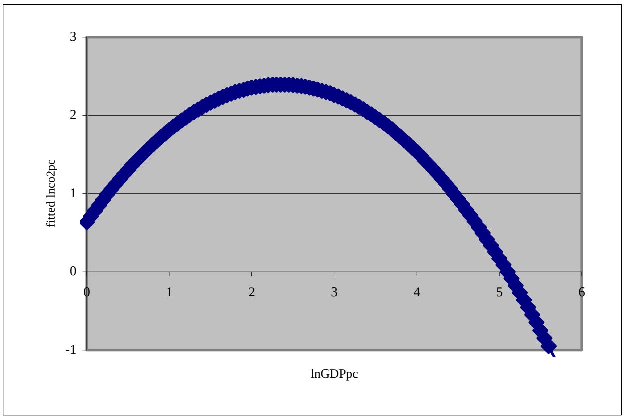
Out of sample

**Figure 1** (cont'd)

(g) United Kingdom



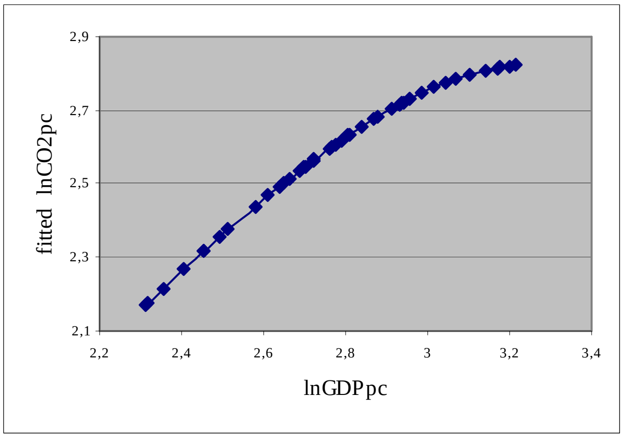

In sample



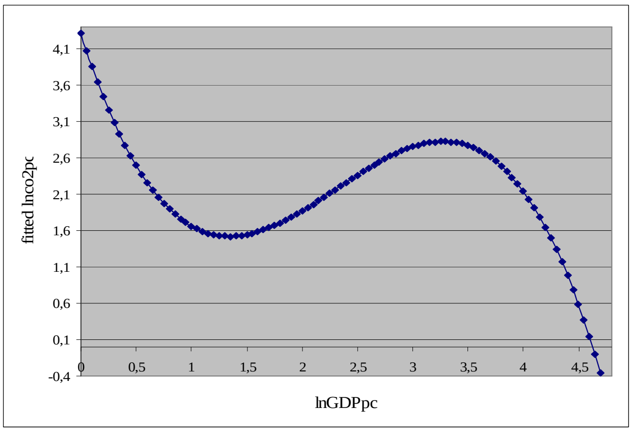

Out of sample

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

(a) Australia

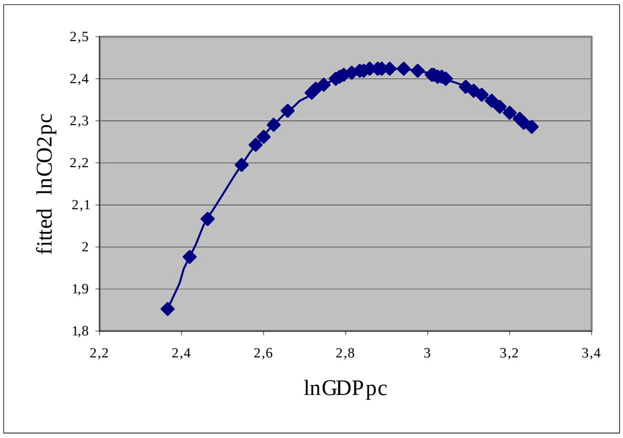



In sample

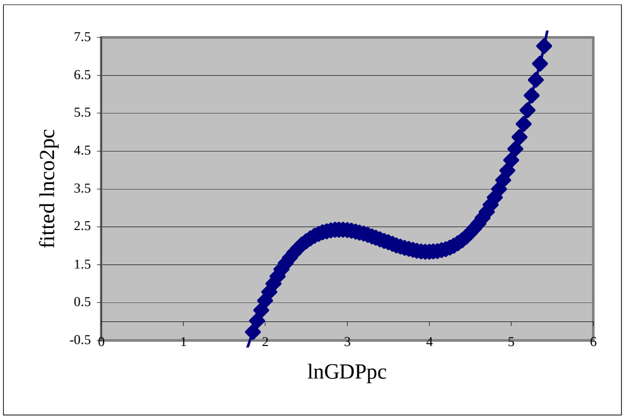



Out of sample

(b) Denmark

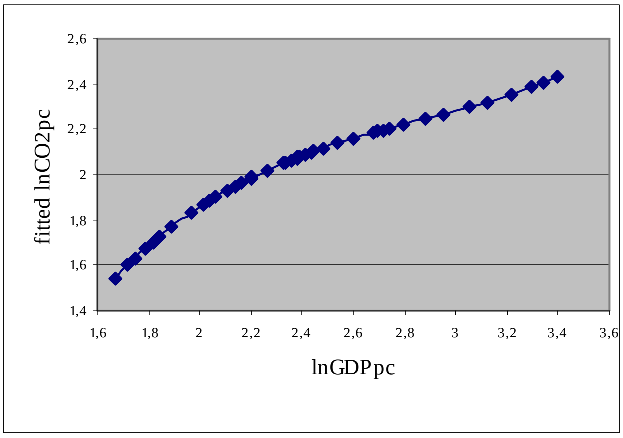



In sample

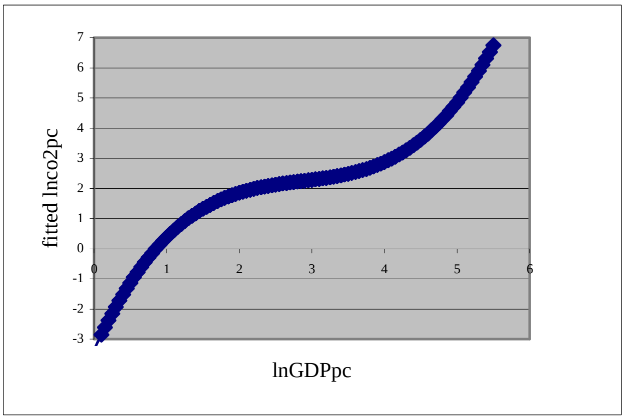



*b*. Out of sample

(c) Ireland




In sample

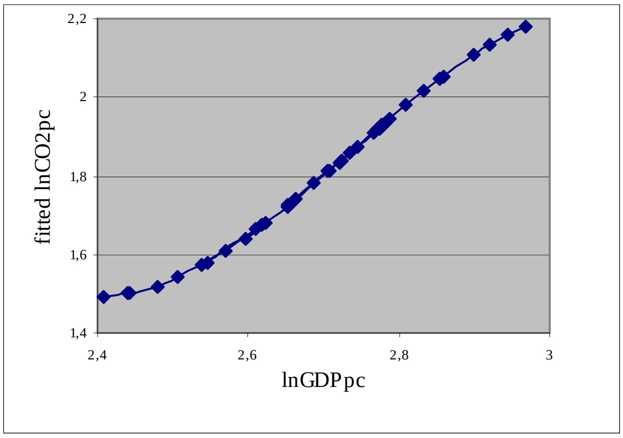



Out of sample

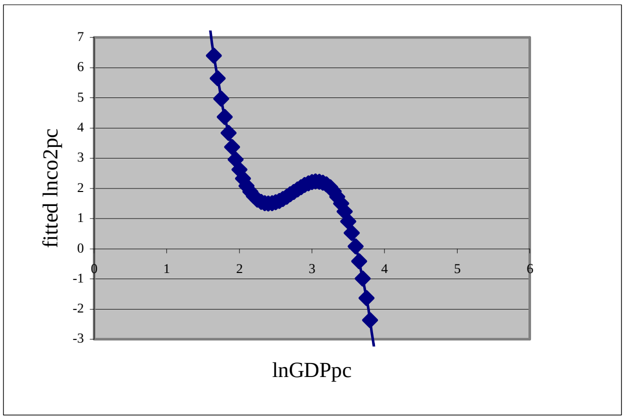
<u>*Notes to Figures 2*</u>. See notes to Figure 1.

**Figure 2** (cont'd)

(d) New Zealand

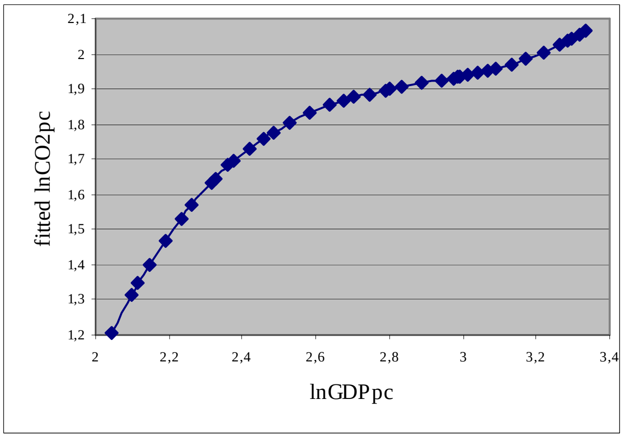



In sample

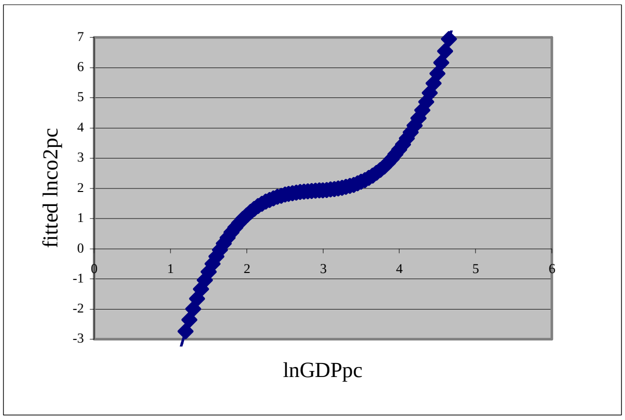



Out of sample

(e) Norway

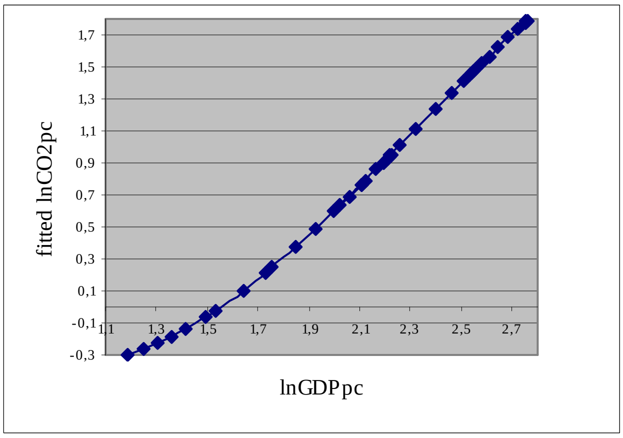



In sample

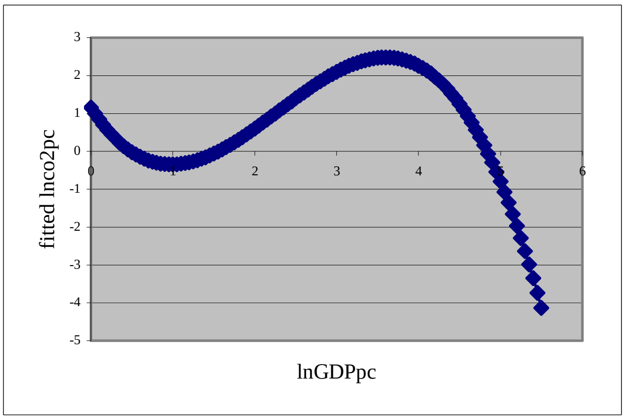



Out of sample

(f) Portugal



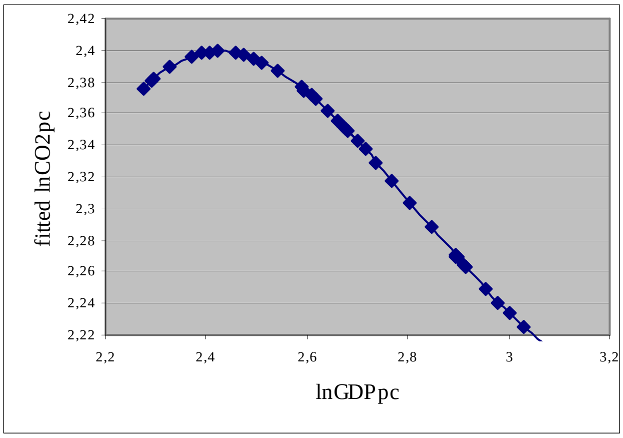

In sample



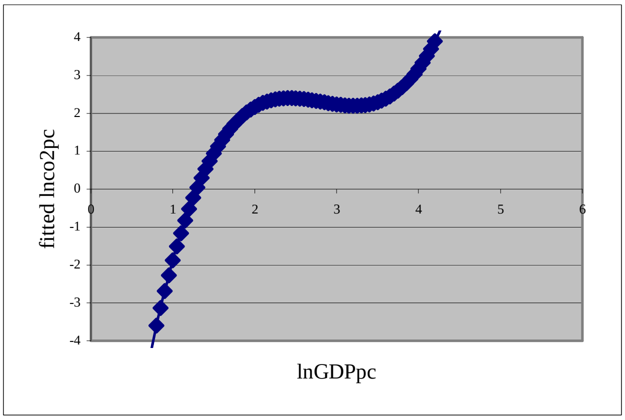

Out of sample

**Figure 2** (cont'd)

(h) United Kingdom




In sample




Out of sample

**NOTE DI LAVORO DELLA FONDAZIONE ENI ENRICO MATTEI**

**Fondazione Eni Enrico Mattei Working Paper Series**

**Our Note di Lavoro are available on the Internet at the following addresses:**

http://www.feem.it/Feem/Pub/Publications/WPapers/default.html
http://www.ssrn.com/link/feem.html
http://www.repec.org
http://agecon.lib.umn.edu

**NOTE DI LAVORO PUBLISHED IN 2006**

| | | |
|---|---|---|
| SIEV | 1.2006 | *Anna ALBERINI:* Determinants and Effects on Property Values of Participation in Voluntary Cleanup Programs: The Case of Colorado |
| CCMP | 2.2006 | *Valentina BOSETTI, Carlo CARRARO and Marzio GALEOTTI*: Stabilisation Targets, Technical Change and the Macroeconomic Costs of Climate Change Control |
| CCMP | 3.2006 | *Roberto ROSON*: Introducing Imperfect Competition in CGE Models: Technical Aspects and Implications |
| KTHC | 4.2006 | *Sergio VERGALLI*: The Role of Community in Migration Dynamics |
| SIEV | 5.2006 | *Fabio GRAZI, Jeroen C.J.M. van den BERGH and Piet RIETVELD*: Modeling Spatial Sustainability: Spatial Welfare Economics versus Ecological Footprint |
| CCMP | 6.2006 | *Olivier DESCHENES and Michael GREENSTONE*: The Economic Impacts of Climate Change: Evidence from Agricultural Profits and Random Fluctuations in Weather |
| PRCG | 7.2006 | *Michele MORETTO and Paola VALBONESE*: Firm Regulation and Profit-Sharing: A Real Option Approach |
| SIEV | 8.2006 | *Anna ALBERINI and Aline CHIABAI*: Discount Rates in Risk v. Money and Money v. Money Tradeoffs |
| CTN | 9.2006 | *Jon X. EGUIA*: United We Vote |
| CTN | 10.2006 | *Shao CHIN SUNG and Dinko DIMITRO*: A Taxonomy of Myopic Stability Concepts for Hedonic Games |
| NRM | 11.2006 | *Fabio CERINA* (lxxviii): Tourism Specialization and Sustainability: A Long-Run Policy Analysis |
| NRM | 12.2006 | *Valentina BOSETTI, Mariaester CASSINELLI and Alessandro LANZA* (lxxviii): Benchmarking in Tourism Destination, Keeping in Mind the Sustainable Paradigm |
| CCMP | 13.2006 | *Jens HORBACH*: Determinants of Environmental Innovation – New Evidence from German Panel Data Sources |
| KTHC | 14.2006 | *Fabio SABATINI*: Social Capital, Public Spending and the Quality of Economic Development: The Case of Italy |
| KTHC | 15.2006 | *Fabio SABATINI*: The Empirics of Social Capital and Economic Development: A Critical Perspective |
| CSRM | 16.2006 | *Giuseppe DI VITA*: Corruption, Exogenous Changes in Incentives and Deterrence |
| CCMP | 17.2006 | *Rob B. DELLINK and Marjan W. HOFKES*: The Timing of National Greenhouse Gas Emission Reductions in the Presence of Other Environmental Policies |
| IEM | 18.2006 | *Philippe QUIRION*: Distributional Impacts of Energy-Efficiency Certificates Vs. Taxes and Standards |
| CTN | 19.2006 | *Somdeb LAHIRI*: A Weak Bargaining Set for Contract Choice Problems |
| CCMP | 20.2006 | *Massimiliano MAZZANTI and Roberto ZOBOLI*: Examining the Factors Influencing Environmental Innovations |
| SIEV | 21.2006 | *Y. Hossein FARZIN and Ken-ICHI AKAO*: Non-pecuniary Work Incentive and Labor Supply |
| CCMP | 22.2006 | *Marzio GALEOTTI, Matteo MANERA and Alessandro LANZA*: On the Robustness of Robustness Checks of the Environmental Kuznets Curve |

(lxxviii) This paper was presented at the Second International Conference on "Tourism and Sustainable Economic Development - Macro and Micro Economic Issues" jointly organised by CRENoS (Università di Cagliari and Sassari, Italy) and Fondazione Eni Enrico Mattei, Italy, and supported by the World Bank, Chia, Italy, 16-17 September 2005.

**2006 SERIES**

| | |
|---|---|
| **CCMP** | *Climate Change Modelling and Policy* (Editor: Marzio Galeotti ) |
| **SIEV** | *Sustainability Indicators and Environmental Valuation* (Editor: Anna Alberini) |
| **NRM** | *Natural Resources Management* (Editor: Carlo Giupponi) |
| **KTHC** | *Knowledge, Technology, Human Capital* (Editor: Gianmarco Ottaviano) |
| **IEM** | *International Energy Markets* (Editor: Anil Markandya) |
| **CSRM** | *Corporate Social Responsibility and Sustainable Management* (Editor: Sabina Ratti) |
| **PRCG** | *Privatisation Regulation Corporate Governance* (Editor: Bernardo Bortolotti) |
| **ETA** | *Economic Theory and Applications* (Editor: Carlo Carraro) |
| **CTN** | *Coalition Theory Network* |