The Stability of the Adjusted and Unadjusted Environmental Kuznets Curve

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Summary

In our paper, we test the stability of the unadjusted and adjusted Environmental Kuznets Curve (EKC). Our results provide evidence in favour of the significance of the adjusted EKC hypothesis in which the impact of per capita GDP on the intensity of CO2 emissions is evaluated conditionally to the effects of the energy-supply infrastructure and of additional socio-demographic variables. In this framework, the GDP-CO2 relationship appears robust to the inclusion of additional regressors and to changes in the estimation period and interval.

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1.1 Introduction

"in poor countries people value more material well-being over environmental amenities, but once a country reaches a sufficient high per capita income, people give greater attention to the environment".
López and Mitra (2000, p. 137)

The Environmental Kuznets Curve (EKC) hypothesis postulates the existence of an "Inverted-U" shape relationship between per capita GDP and measures of environmental degradation (Panayotou, 1993 and 2000; Grossman-Krueger, 1991 and 1995; Selden-Song, 1994; Shafik-Bandyopadhyay, 1992; Hettige-Lucas-Wheeler, 1992, Koop, 1998). The rationale for this hypothesis is that pollution has significant health and environment effects and high abatement costs. As far as income grows, the demand for health and environmental quality rises and the production mix moves toward more information-intensive activities. Therefore, the marginal cost of pollution becomes much higher leading to a lower level of emissions in equilibrium (Holtz-Eakin-Selden, 1992).

Following Galeotti (2003a), it is possible to decompose this general statement into three different traditional explanations for the EKC relationship.

The first is based on the well-known “stages of economic growth” argument, according to which environmental degradation tends to increase when the economy moves from an agricultural to an industrial-based structure, while, in a further stage, it moves from an industrial-based to a service intensive, technological-based system.

The second rationale focuses on the “technological progress” argument and on the effects of R&D spending. According to it, the oil crisis fostered the research on new sources of electric power production. Technical changes arising from this research allowed to use inputs in a more efficient way, reducing waste and substituting natural inputs with recycling inputs (Unruh-Moomaw, 1998).

Finally, a third demand side rationale hinges on the consideration that environmental quality is a “luxury good”. According to it, only after reaching a certain income threshold, and after satisfying the consumption of primary goods, individuals begin to demand for less air and water pollution. In this sense, the EKC is the consequence of consumer choices more than an effect of the evolution of domestic economic systems. (Hill and Magnani, 2002).

1.2 Empirical findings and limits to the stability and the generalisation of the EKC curve

The traditional and simple specification including levels and squares of real per capita GDP has been challenged and shown to be subject to the omitted variable bias given its strong sensitiveness to the inclusion of additional covariates.

The recent theoretical and empirical literature[1] highlights that several additional variables significantly affect measures of environmental degradation after controlling for per capita GDP. Some authors emphasize the role of energy prices showing that an increasing level of oil prices implies a reduced use of fossil sources. CO_2 emissions declined during the period between 1979 and 1982 after the oil price shocks as a result of substitution of productive processes, while, on the other hand, since 1985, they have steadily risen after oil prices started declining significantly (Holtz-Eakin-Selden, 1992 and 1995, Agras-Chapman, 1999).

Lopez-Mitra (2000) postulate in their theoretical model that, for any level of per capita income, the rent-seeking behaviour of corrupt governments raises pollution above the social optimum. Stern-Common-Barbier (1996) assume that technological change toward information intensive industries reduce emissions for a given level of per capita income. Even though international trade is expected to affect the EKC there is no consensus on the direction and the nature of the impact. Grossman-Kruger (1991) test the role of trade openness on the improvement of environmental quality but do not find any significant relationship between trade and pollution. Suri-Chapman (1998) and Agras-Chapman (1999) show the positive impact of trade in manufactured goods on environmental quality. For several authors (Antweiler-Copeland-Taylor, 1998; Frankel-Rose, 2002) free trade is good for the environment since it may accelerate the growth process in developing countries.

Magnani (2000) finds that other moments of the income distribution matter and that within-country income inequality reduces the demand for pollution abatement.

Rothman (1998) provides an important caveat on the interpretation of the Kuznets curve results, pinpointing that "*what appear to be improvements in environmental quality may in reality be indicators of increased ability of consumers in wealthy nations to distance*

[1] For a detailed survey on theoretical and empirical literature see Borghesi (1999) and Panayotou (2000).

themselves from the environmental degradation associated with their consumption". According to this hypothesis, high-income countries could maintain the same polluting potential and reduce their per capita emissions by moving more polluting industries, or ways of producing energy, outside their borders.

Many of these empirical papers question the robustness of the EKC.

Levinson (2001) shows that the carbon dioxide emission index shows even a "N-shape" path relative to income due to cross-border externalities, reducing domestic incentives to commit themselves to respect international rules on the reduction of CO_2 emission.

Galeotti (2003b) simulation analysis, based on the Nordhaus's RICE model, shows that an inverted-U shape does not exist when countries do not have environment protection rules and technical change is productivity enhancing. He also finds out that the introduction of "green technologies" has a positive effect on emissions since the positive slope of the environment-income relationship decreases, but it is not sufficient to turn it to negative.

Galeotti-Lanza-Pauli (2004) test whether the environment-income relationship is robust to changes in the functional form and data sources. Considering a three-parameter Weibull function and the database developed by International Energy Agency (IEA), their results show that the EKC depends not only on the source of the data, but also on the functional form. In fact, the inverted-U shape is evident only for the OECD group of countries with both the new data set and the old one. On contrary, non-OECD countries show an increasing slope with the IEA data, but they confirm an inverted-U shape form with the old ones.

In recent contributions, increasing attention has been given to the fact that the Kuznets curve is quite unstable over time (Dasgupta et al., 2002; Harbaugh et al., 2002). In particular, Roberts and Grimes (1997) have shown the instability of EKC (from linear to inverted-U shape) considering the relationship between per capita GDP and national carbon intensity, defined as CO_2 emissions per unit of GDP.

Last but not least, an important issue which has not yet fully solved in the EKC empirical literature, and which is the object of the recent research, is how to deal with the problem of non-stationary and cointegration in EKC estimates. As it is well known, testing for cointegration requires in panel data ad hoc diagnostics, different from the standard and well established techniques used in time series analysis. From the battery of the proposed empirical tests the heterogeneous approach developed by Im, Pesaran and Wagner (2004) to detect non-stationarity (dealing with the possibility that time series of some individuals have unit roots and other not) seems to be the best candidate. In case of evidence for unit roots non-stationary, cointegration may be tested by using the group mean approach developed by Pedroni (2004). When individual time series are short these tests should be accompanied by bootstrap critical values (Müller-Furstenberger, Wagner and Müller, 2004)[2]. An additional test for cointegration is the one developed by Nyblom and Harvey (2000).[3] The test does not require any models to be estimated, even if serial correlation is present, and therefore it is particularly convenient in presence of nonlinear specifications such as that of the EKC.

In view of all the considerations developed above additional research on the EKC is welcome for at least two reasons.

A test on the relevance of EKC hypothesis is important not only for solving the controversy on its robustness, but also from a normative point of view. If the EKC holds, it can be a valid

[2] When Müller-Furstenberger et al. (2004) apply these techniques to a panel of 107 countries with annual data from 1986 to 1998, they find evidence of non-stationary, but reject the null of no-cointegration. However, they correctly argue that the final problem of the application of specific panel cointegration techniques dealing with nonlinear specifications such as that of the EKC (where log of per capita GDP and its square appear together as regressors) is far from being successfully solved.

[3] The Nyblom and Harvey test may be considered as a generalization of the Nyblom and Makelainen (1983) and Kwiatkowski et al. (1992) univariate tests for stationary of a series. Those tests are of the null hypothesis that the series is stationary, or stationary around a deterministic trend, against the alternative that a random walk component is present.

tool for evaluating deviations from "fair" or acceptable pollution quotas in a framework in which the global emission threshold is established in international agreements and pollution rights are exchanged among different countries.

Moreover, and from a more general point of view, the Kuznets curve may represent the benchmark for out of sample forecasts on the dynamics of pollution and, therefore, may be an important tool for discriminating between optimistic and pessimistic hypotheses over the future of the world environment (Holtz-Eakin-Selden, 1992 and 1995).

1.3 Our approach to explain EKC lack of robustness

Our opinion is that empirical findings on the fragility of the Kuznets curve are the expected outcome of the complex interaction among time varying: i) supply factors (such as the use of fertilizers in agriculture, or the use of gas, coal, oil or hydroelectric power for the production of energy); ii) demand factors (the traditional argument of environment being a luxury good); iii) regulatory factors (results of the interaction between increasingly environmentally aware constituencies and policymakers), iv) trade relationships among different countries (the dynamics of import/export of energy according to various trade theories such as the "race to the bottom hypothesis" of Dasgupta et al. (2002).[4]

This is why we miss the interaction between all these factors and their changes when we measure a cross-sectional Kuznets curve over long time spells without considering its potential variability in time.

[4] The "*race to the bottom*" hypothesis described by Dasgupta et al. (2002) assumes that support of high environmental standards in developed countries is so costly that shareholders have the incentive to relocate their firms into low-income countries, where environmental legislation is weak or non-existent. To prevent these outflows of capital, rich countries have to relax their environmental standards themselves. As a consequence of this race to the bottom, the EKC hypothesis is no more supported since the curve flattens and rises toward the highest existing level of pollution.

For this reason, we intend to compare in the paper a long run fixed effect panel estimate over a 40-year time horizon with rolling period panel fixed effect estimates to test whether the Kuznets curve has significantly changed across time. The use of fixed effects helps us to capture country specific time invariant factors affecting pollution intensity which are not captured by our regressors (eg. differences in domestic climatic factors which affect heating decisions which are quite difficult to measure with existing data). Moreover, taking into account and going beyond suggestions from the above mentioned empirical literature, we depart from the traditional specification (which we define in the paper as unadjusted EKC) by conditioning the per capita GDP effect on environmental degradation not only to social variables, but also to measures of production of energy and use of fertilizers as proxies of supply side effects on CO_2 emissions. In this way we propose an alternative adjusted specification for the EKC whose relevance will be tested in the empirical analysis.

Empirical contributions on the EKC generally use as dependent variable a measure of environmental degradation scaled by population, even though examples of using GDP as a scale factor also exist (Roberts-Grimes, 1997). In this paper, we choose the second approach since we argue that this approach is more related to the core of the current debate between economists and environmentalists. The main problem between the two stems from the different scientific background (and, often, the lack of consideration for the scientific background of the other group) and generally leads to conflicting policy prescriptions. On the one side, economists focus on the problem of creation of value and fight to poverty, give limited consideration to environmental and resource constraints and suggest to grow more. On the other side, environmentalist focus on the problem of environmental degradation, give limited consideration to the development constraint and suggest to grow and consume less. The only possible synthesis which keeps into account the goals of both, and the resource and development constraint at the same time, is the search for a "lighter economy" in which the environmental degradation per value created is progressively reduced. Indicators of environmental degradation, scaled by GDP, measure exactly the degree of "lightness" of an economy and therefore go deeper at the core of this issue than traditional measures in which environmental degradation is scaled by population. This explains our choice.

Within this framework, the remainder of the paper is organized as follows. Section 2 presents descriptive findings on the chosen measure of environmental degradation (CO_2 emissions per GDP) and its potential determinants. Section 3 presents econometric findings illustrating the differences between overall period and short run rolling fixed effect panel estimates of the unadjusted and adjusted EKCs. Some conclusions are drawn in the final section.

2.1 Descriptive findings

We build our sample by extracting a panel dataset from the World Development Indicators (WDI) database. We select 197 countries all over the world (for the complete list of constituents see table A.1 in APPENDIX A).

Data are collected yearly for a period of 42 years beginning in 1960 and finishing in 2001. They include emissions from aggregate fossil fuels consumed by domestic systems. This measure of carbon dioxide emissions allows us to analyse supply side effects, with particular reference to scale and technology factors described by Panayotou (2000) and Borghesi (1999). According to the authors, changes in the industrial structure are the main aspect that characterises the shape of the Kuznets curve. Along the path of economic development, a country changes its supply structure from a mainly agricultural to a prevalently industrial system and, in a final step, to an increasingly important role of service intensive industries such as those of information and communication technology. The first and second step should characterise the upside of the curve, while the third phase could explain the downward slope of the EKC.

Consistently with the above described arguments in the literature, we select - in addition to per capita GDP - the following variables as potential determinants of CO_2 emissions: i) supply side variables such as sources of energy production (coal, oil, gas, hydro and nuclear power as a percent of total energy production for domestic use);[5] ii) inputs and proxies of agricultural activity such as the number of tractors per 1000 inhabitants and the intensity in the use of fertilisers; iii) population density so that it is possible to compare under-populated countries with over-populated countries and their contributions to the overall environment degradation; iv) social variables which are usually added as proxies of given moments in the distribution of income (respectively, the number of radios and telephone mainlines per 1000 inhabitants) or, alternatively, as proxies of the weight of information-intensive activities which should increase the marginal cost of pollution and the share of less environmentally degrading non rivalrous goods in the economy (Holtz-Eakin-Selden, 1992 and 1995); v) fuel import (as a percent of total commercial imports) to evaluate the marginal effect on domestic pollution of the country capacity to distance itself from environmental degradation (Rothman, 1998).

In Tables 1 and 2, we present some descriptive statistics of the variables considered for both specifications on the overall sample.

[5] The different impact of sources of energy production on environmental degradation has sound scientific foundations. The IPCC Guidelines for National Greenhouse Gas Inventories identify the following emission factors (expressed in CO_2 tons per Terajoule produced) for the following sources: i) liquid fuels (crude oil 72.55; GPL 62.39, oil 68.56; Kerosene 70.74 gasoil 73.27); ii) solid fuels (90 steam coal 94.58, 95 steam coal 94.01; coking coal 92.64; sub-bitumen coal 96.23, Lignite 99-.11, Coke 105.93); iii) natural gas 55.80. The emission factor for liquid fuels (oil, gasoil) is therefore around 70 percent and that of natural gas around 55 percent of that for solid fuels. Consider also that hydro electrical power does not create energy with combustion and therefore its production of CO_2 (limited to some effects generated by water basins) is negligible.

Table 1 shows a quite strong correlation between our measure of environmental degradation and per capita income (-.55). It is interesting to verify whether this relevant linear correlation is compatible with the inverted U-shaped relationship postulated by the EKC hypothesis.

The two proxies of the distribution of per capita GDP and of the share of "weightless" ICT-intensive economy, radio and telephone mainlines, also present a negative correlation with our indicator of pollution (respectively -.27 and -.47). We finally observe a quite strong positive relationship between environmental degradation and coal as a source of energy production (.34), while the correlation of the former with other sources of energy production is much weaker (Table 1).

Information on the distribution of selected regressors is provided by Table 2. It shows that coal is still in the overall period the most important source for energy production (33.4 percent) followed by oil (31.6 percent) and gas (26.19 percent). If we observe though, the dynamics of these variables for countries divided into income subgroups[6] in the period covered by our data (1960-2002) we find that: i) the use of coal is decreasing in lower income and increasing in lower-middle income countries as it is confirmed in the previous columns where South Asian and Sub-Sahara African countries have a coefficient with negative sign; ii) the use of gas is increasing in all subgroups with the exception of upper-middle income countries; iii) the use of oil is decreasing in all subgroups (Tables 3.1-3.3).

In table 3.4, we observe that, at the end of the estimation period, gas has turned to be the most important source of energy only for the low income countries, while coal remains the main of source of energy production for all other income subgroups.

Before estimating our model we test for the presence of unit roots in our variables by using some recent tests developed on panel data. In table 4.1 we show the critical value of the test

[6] *Low-Income Economies* up to $745, *Lower-Middle-Income Economies* between $746 and $2,975, *Upper-Middle-Income Economies* between $2,976 and $9,205, *High-Income Economies* more or equal to $9,206.

for unit roots in heterogeneous panels developed by Im et al. (2003). The Im et al. (2003) test is based on the mean of the individual Dickey-Fuller *t-statistics* of each unit in the panel and assumes that all series are non-stationary under the null hypothesis (H_0: ρ_i=1) against the alternative heterogeneous hypothesis (H_1: ρ_i <1 for each i=1,…,N_1 and ρ_i =1 for each i=N_1+1,…,N for some N_1)[7]. The formulation of this hypothesis allows for a dynamic behaviour different across countries and also for the presence of unit roots for some (but not all) countries. Unlike the Levin and Lin (1993) test, which assumes under the alternative that all series are stationary, in the IPS test the null hypothesis is tested against the alternative that only a fraction of the series are stationary.

In table 4.1, we test all the variables of our empirical analysis assuming a "fixed effects only" structure in the upper block-rows and a "fixed effects and time trends" structure in the lower block-rows[8]. Moreover, we report test statistics under the hypothesis of serially uncorrelated (*t-bar*) and serially correlated (*W-bar*) errors. This second case is the more general case in which serial correlation patterns across groups are different, with *T* and *N* sufficiently large as in our empirical analysis.

The test reveals that the majority of the variables in our analysis have unit roots in their time series dimension. In particular the *t-bar* value of the logarithm of per capita GDP (-1.21) is inferior to all critical values (10%, 5% and 1%) and even the *W-bar* value is below that threshold. The intensity of carbon dioxide emissions shows the presence of unit roots (*t-bar* = -1.67) only at the significant level of 5% and 1% and the same result in the case of serially correlated errors.

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[7] The homogeneous hypothesis is that H_1: $\rho_i = \rho < 1$ implying that variables are generated by a stationary process, identical across countries.

[8] We are interested in testing for the presence of unit root in a stochastic process x_{it} generated by the first-order autoregressive model including fixed effects and time trends: $x_{it} = \rho_i x_{it-1} + \alpha_i + \gamma_i t + u_{it}$ where u_{it} is a stationary process.

For both variables the results are confirmed under both the fixed effects only and the fixed effect with time trend specification.

For the majority of the additional variables we introduce in our specification, we can show the presence of unit roots in both specifications of the autoregressive process (fixed effects and fixed effects plus time trends).

Because of the presence of unit roots, we need to test whether these variables are cointegrated (i.e. share a common stochastic trend) in order to obtain meaningful regression results with estimates in levels. The test, we perform, is based on Nyblom-Harvey (2000) and may be considered as a generalization of the Nyblom and Makelainen (1983) and Kwiatkowski et al. (1992) univariate tests for stationary of a series. The null hypothesis of those tests is that the series is stationary, or stationary around a deterministic trend, against the alternative of the presence of a random walk component. The test considers the same structure in the context of multiple time series. In particular, the "test can be regarded as a test of the validity of the hypothesis that there are a certain number of common trends." (Nyblom-Harvey, 2000, p. 177). Its advantage is that it does not need a model to be estimated because is based on the rank of covariance matrix of the disturbances driving the multivariate random walk. If this rank is equal to a certain number of common trends, this implies the presence of cointegration and vice-versa. If the rank is equal to zero, as in the null hypothesis, then there are no common trends among the variables. Thus, a failure to reject the null hypothesis of zero common trends is also an indication that the variables do not form a cointegrated combination.

In table 4.2 are reported the test statistics under both the IID (*NH-t*) and the serially correlated residuals (*NH adj-t*) assumptions. The test is calculated under the two different model specifications (fixed effects only and fixed effects plus time trends). The results show that under the first specification (fixed effects only) the null hypothesis is rejected in the case of serially correlated errors. On the contrary, if we introduce time trends in the autoregressive process, we find the presence of cointegrating vectors both under the IID and serially correlated errors assumption.

These diagnostics lead us to conclude that the EKC model can be estimated with variables in levels in our sample.

3.1 Econometric findings

The main interest of our analysis is to verify the existence and stability over time of the unadjusted and adjusted EKCs. To achieve this result, we follow the standard specification of a quadratic function where the intensity pollution index is the dependent variable and the production level measured by per-capita GDP (in levels and squares) the independent variable. The classical unadjusted EKC specification is extended by including other variables which proxy for the effects on environmental degradation induced by the energy and agricultural production structure and by various measures of trade and income distribution.

Our specification is:

$$\begin{aligned} CO_{2it} &= \alpha_0 + b_1 GDPPC_{it} + b_2 (GDPPC)^2_{it} + b_3 COAL_{it} + b_4 GAS_{it} + b_5 OIL_{it} + b_6 TRACTORS_{it} + \\ &+ b_7 FERT_{it} + b_8 POP_{it} + b_9 RADIO_{it} + b_{10} TELEPH_{it} + b_{11} FUELIMP_{it} + u_i + \varepsilon_{it} \end{aligned} \quad (1)$$

where CO_2 is the intensity of carbon dioxide emissions (kg in 1995 US$ of GDP) stemming from the burning of fossil fuels (solid, liquid and gas fuels). National carbon intensity (CO_2), is calculated by World Bank using data of Carbon Dioxide Information Analysis Center (CDIAC) divided by gross domestic product at constant 1995 US dollar. Following Roberts and Grimes (1997), this indicator could be consider as the best index to capture intensity of carbon emission by country's production. Regressors include GDPPC which measures per capita GDP (based on constant prices of 1995 in US$); COAL, GAS and OIL are sources of electricity and represent the inputs used to generate electricity for all the national requirements. These indicators refer to the share of total electricity production generated from coal, gas and oil. In particular, electricity production is measured at the terminals of all alternator sets in a station and includes the output of electricity plants that are designed to produce electricity only as well as that of combined heat and power plants. TRACTORS, is the per capita agricultural machinery, refers to the number of wheel and crawler tractors in use in agriculture divided by the total number of population; FERT is the per capita fertilizer consumption calculated as hundred grams per hectare of arable land. It measures the quantity of plant nutrients used per unit of arable land. Fertilizer products cover nitrogenous, potash, and phosphate fertilizers (including ground rock phosphate). The time reference for fertilizer consumption is the crop year (July through June). The POP variable measures population density that is midyear population divided by land area in square kilometres. In particular, population is based on the de facto definition of population, which counts all residents regardless of legal status or citizenship--except for refugees not permanently settled in the country of asylum, who are generally considered part of the population of their country of origin. RADIO is the number of radios receivers in use for broadcasts per 1,000 people; TELEPH, is telephone mainlines per 1,000 people in other words is telephone lines connecting a customer's equipment to the public switched telephone network. Finally, FUELIMP, fuel imports (as a percent of merchandise imports) comprise the commodities in the United Nation' Standard International Trade Classifications (SITC)[9]. In the model the variable u_i measures fixed effects proxying the impact on pollution intensity of time invariant country specific variables not captured by the above considered regressors.

The model is estimated on the overall period and in 20-year moving windows in order to investigate the dynamics of the EKC in the last decades.

The Hausman test confirms the absence of orthogonality between the set of regressors and residuals suggesting that the fixed effect model should be used instead of the random effect model (see Table 5).

Evidence from the 1960-2000 base specification of the Kuznets curve gives the idea of a significant inverted U-shape relationship between the intensity of CO_2 emissions and per capita GDP (Table 5). Parameters significance is quite strong and with the expected sign.

An important aspect of our findings is that the predicted maximum point of the estimated EKC is not always below the mean value of per capita GDP in the sample. This is not consistent with Selden and Song (1994) arguing that the upward-side of the curve is very small and the majority of the countries are in the downward side of EKC. If the base specification is extended, the GDP effect is still robust when conditioned to supply and demand side effects. Since the Kuznets curve is both a cross-sectional and a time-series phenomenon it is interesting to see that the within (time-series) effect prevails when we abandon this simple specification and condition for supply and socio-economic factors. Goodness of fit is largely improved by the inclusion of additional regressors, even though the number of observations is much smaller. The within (overall) R-squared goes from .02 (.01) in the unadjusted EKC to .63 (.16) in the adjusted EKC specification (Table 5). To avoid the risk that differences of results between unadjusted and adjusted EKC specifications are

[9] In Section 3 (mineral fuels) the SITC Rev3 of 1994, a unified commodity classification system capable of spanning different countries and time periods, describes all the commodities related to mineral fuel such as i)

determined by sample bias, we re-estimate the model with a constant number of observations (Table 5). Results are not substantially different with all regressors remaining significant and with the expected sign. The within (overall) R-squared in the unadjusted case is equal to .56 (.74) while in adjusted EKC we get a within (overall) R-squared corresponding to .63 (.16).[10]

On the overall, the introduction of sources of energy production dramatically improves estimates providing by itself a contribution of almost fifty percent of goodness of fit in within group significance. If we look at coefficient magnitudes of different sources of energy production we find that they become broadly consistent with IPPC emission factors described in footnote 3 once other regressors of the adjusted specification are taken into account.

Inputs of agricultural activity (number of tractors and intensity in the use of fertilizers) are also significant and with the expected sign.[11]

The POP variable measures population density which is another important dimension to consider when evaluating the effects of population on the income-environment relationship. According to Panayotou (1997, 2000), population density affects per capita CO_2 emissions net of the expected per capita income effect, but it is difficult to hypothesize a priori in which direction.

On the one hand, we expect that, the higher population density, the higher the intensity of CO_2 emissions due to the increased intensity in the use of energy for production and other needs. On the other hand, we might expect that pollution rises less than proportionally in the increase of population and that more densely populated countries will develop a higher environmental demand for abating CO_2 emissions.

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coal and coke; ii) petroleum, petroleum products and related materials; iii) gas, natural and manufactured

[10] The dramatic jump in goodness of fit when we move to the constant observation sample (passing from more than 4000 to 611 observations) shows that the inclusion of countries in which data are only more recently available (including small developing countries and tropical isles) sharply increases dispersion in our estimates.

[11] According to the previously mentioned rationales signs of the agricultural variables are expected to be positive. This is because, a more intensive use of technologies for improving the quantity of harvest produced in a year affects air polluting emissions.

Our results in Table 5 show that the population density coefficient has positive sign. These results confirm that pollution rises more than proportionally in the number of inhabitants so that national carbon intensity is positively correlated with the amount of population in a geographical area.

Among remaining regressors, diffusion of radios and telephone lines is shown to be strongly significant among socio-economic variables. The rationale for using these variables is that they proxy wealth of the lowest centiles of population. The expected and significant negative sign does not contradict the hypothesis that these variables, inversely related to the dimension of the lowest centiles of the income distribution, show that the relationship between income and emissions should be evaluated, not only looking at the mean but also at other moments of the income distribution itself. An alternative but observationally equivalent hypothesis is that the two variables signal a more information-intensive mix in the industrial activity with positive effects on the reduction of emissions (Holtz-Eakin-Selden, 1992 and 1995). This interpretation supports the hypothesis that a more service and ICT intensive economy is associated to a higher share of non rivalrous, intrinsically less goods,[12] thereby reducing the environmental degradation associated with value creation.

Including the fuel import variable, we want to test the relationship between pollution and fuel domestic consumption. Our assumption of a positive relationship is not supported by our estimates, given that the sign is negative and not very significant.

At the end of this first part of the analysis, we focus again on the estimated value of turning point. As it can be easily seen in Table 5 the value of the maximum point is not very far from those obtained in the literature which uses per capita CO_2 emissions as a dependent variable

[12] A non rivalrous good (eg. CDs, videotapes, software) does not need to be produced again once it has been consumed by a specific consumers.

(Grossman-Krueger, 1995), even though some authors such as Holtz-Eakin-Selden (1992 and 1995) and Schmalensee et al. (1998) have found higher values.

3.2 The rolling period analysis

We perform a robustness check on results presented in Table 4 by evaluating the impact of additional regressors in the adjusted EKC when adding them one by one to the unadjusted specification.[13] These findings show that all considered regressors are quite stable to changes in the specification and to the inclusion of additional variables. To evaluate the stability over time of the unadjusted and adjusted EKC hypotheses we re-estimate them in 20-year rolling periods (with and without constant number of observations) starting from the first sample year (1960) and ending in 2001.

The use of rolling periods in fixed effects panel estimates is convenient also because it does not require the unrealistic assumption that country specific fixed effects are invariant over too long periods of time.

The rolling estimate for the base two-regressor specification clearly shows that the shape of the unadjusted EKC varies across time (Tables 6.1-6.2). The general result of this robustness analysis shows that findings related to the adjusted and unadjusted EKC specifications are rather robust to the choice of the time interval and period. Actually, both the unadjusted and adjusted form of EKC (in estimations with and without constant number of observations) show an inverted-U shape in the final periods (Tables 6.1-7.2). Instead both non constant and constant observation adjusted estimations demonstrate the inexistence of a maximum point in the first periods of the 20-year rolling periods. The problem seems to be strongly related,

[13] Results are omitted and available from the authors upon request.

though, to the drastically lower number of degrees of freedom in the estimates of older time intervals.

The stability of coefficients significance and sign is remarkable in the unadjusted EKC (from the 1963-1982 to the final 1982-2001 rolling period), while in the adjusted EKC it is strong only after the first periods (from the 1966-1985 to the final 1982-2001 rolling period).

If we focus our attention only on rolling periods in which the coefficients have the expected signs and are significant, we observe that the turning point values (between 100$ and 6000$) are in the most cases superior to the per capita GDP median sample value, but decline in the last periods (Selden and Song, 1994). These results confirm the presence of an environmental demand for pollution abatement even in the developing countries since the decreasing aspect is predominant. The same considerations apply in the adjusted EKC, where the maximum point varies in a range between 100$ and 2500$ (lower than in the unadjusted EKC estimate) and is relatively higher than the median. This implies that, once we take into account the hystheresis of production structures and the effect of social variables, the turning point is realised at lower levels of per capita income in the case of constant number of countries. On contrary, if we consider all countries in the dataset, we find that the maximum point is lower in the case of unadjusted EKC functional form, since it decreases more rapidly than the value of the turning point in the adjusted specification.

4. Conclusions

Harbaugh et al. (2002) in a recent econometric paper demonstrate the lack of robustness of the Kuznets curve when countries, variables and time intervals are changed. These results are the starting point of our analysis which tries to document and interpret how and why the EKC has changed over time. We follow Roberts and Grimes (1997) in choosing the carbon dioxide intensity per unit of GDP instead of per capita CO_2 as a dependent variable since we argue that the former variable is more focused on what appears to be the crucial issue in the pursuit of an environmentally and socially sustainable development: the transition to a “lighter economy” in which creation of value with reduced pollution intensity allows to fight poverty and environmental degradation at the same time.

Our findings show that, once we condition adjusted and unadjusted EKCs to fixed effects and our extended set of regressors including sources of energy production, their stability is quite remarkable. The unconditional EKC is quite robust to changes in the time interval in 20 years rolling estimates, when both changing and constant number of countries are considered, and robust to the inclusion of additional regressors. The GDP - CO_2 relationship holds also when socio-demographic variables and contributions of proxies of energy production and use of fertilizers in agriculture are considered as additional regressors in the model.

The inclusion of additional components has relevant consequences in terms of prediction and policy measures. It shows that, not just higher standards of living, but also more environmental friendly ways of producing energy or new sources of energy production, an increased share of value made by non rivalrous service and ICT intensive goods and an improved distribution of income may contribute to reduce the level of CO_2 intensity per unit of GDP produced.

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Table 1: Partial correlations among intensity of CO_2 emissions and its selected determinants

	CO_2	GDPPC	COAL	GAS	OIL	FERT	TRACTOR	POP	RADIO	TELEPH	FUELIMP
CO_2	1										
GDPPC	-0.55	1									
COAL	0.34	-0.02	1								
GAS	0.05	-0.15	-0.26	1							
OIL	-0.05	-0.19	-0.26	0.09	1						
FERT	-0.21	0.23	-0.003	0.16	-0.08	1					
TRACTOR	-0.31	0.53	0.14	-0.18	-0.22	0.54	1				
POP	-0.08	0.25	0.10	0.24	0.17	0.01	-0.24	1			
RADIO	-0.27	0.56	0.17	-0.06	-0.26	0.05	0.35	0.002	1		
TELEPH	-0.47	0.86	0.09	-0.21	-0.33	0.20	0.59	0.09	0.65	1	
FUELIMP	0.07	-0.06	-0.01	0.02	0.15	-0.16	-0.06	0.24	-0.10	-0.18	1

Variable legend. CO_2: intensity of emission of CO_2 per unit of GDP (kg in 1995 US$ of GDP); GDPPC: per capita GDP (in 1995 in US$); COAL: share of total electricity production from coal; GAS: share of total electricity production from gas; OIL: share of total electricity production from oil; TRACTOR: number of tractors used in agricultural production per 1,000 people; FERT: fertiliser consumption (hundred grams per hectare of arable land); POP: population density (people per km^2); RADIO: radios per 1,000 people, TELEPH: telephone mainlines per 1,000 people; FUELIMP: fuel imports (% of merchandise imports)

Table 2: Descriptive statistics on selected variables in the overall sample

	Mean	Standard error	Median	Standard deviation	Kurtosis	Skewness	Min	Max	Number of observations	Percentiles							
										1%	5%	10%	25%	75%	90%	95%	99%
CO_2	1.05	0.02	0.60	1.41	25.08	4.07	-0.89	15.22	5040	0.06	0.17	0.22	0.37	1.11	2.31	3.39	8.22
GDPPC	5564.61	111.07	1615.46	8489.02	7.91	2.20	0.00001	58486.54	5841	126.91	201.25	256.42	515.81	6348.06	18318.04	24998.86	37896.99
COAL	33.40	0.68	27.04	28.83	2.27	0.65	0.001	99.80	1820	0.03	0.20	1.46	7.66	54.44	76.45	91.58	97.46
GAS	26.19	0.70	13.76	30.49	3.49	1.30	0.001	100	1906	0.04	0.20	0.52	2.94	38.66	84.97	98.91	100
OIL	31.60	0.55	18.64	32.61	2.58	0.97	0.004	100	3573	0.03	0.58	1.41	4.76	50.56	92.31	100	100
FERT	0.003	0.0002	0.00001	0.02	112.65	8.80	0.00001	0.44	6039	0.00001	0.00001	0.00001	0.00001	0.0003	0.002	0.01	0.10
TRACTOR	0.004	0.0001	0.0009	0.01	18.24	3.35	0.00001	0.11	6408	0.00001	0.00001	0.00001	0.0002	0.004	0.017	0.03	0.05
POP	224.31	13.91	45.68	1167.09	157.39	11.59	0.10	20900.00	7037	0.92	2.45	4.89	14.76	127.02	281.18	433.73	4597.00
RADIO	355.84	5.58	254.80	346.40	59.35	4.33	0.26	6763.01	3850	15.21	30.25	49.02	121.04	520.19	786.77	942.88	1421.36
TELEPH	123.55	2.26	47.75	161.83	4.79	1.59	0.00001	869.80	5124	0.50	1.40	2.20	8.00	182.15	388.60	491.50	634.30
FUEL IMPORT	11.97	0.17	9.10	11.42	16.30	2.98	0.0002	94.20	4773	0.29	0.93	2.06	5.35	14.95	23.82	30.90	63.18

Variable legend: see table 1

Table 3.1: Trends in the use of carbon as source of energy production for industrial uses in World Bank macroareas and per capita income subgroups

Ln(COAL)	East Asia and Pacific	Europe and Central Asia	Latin America and the Caribbean	Middle East and North Africa	South Asia	Sub-Saharan Africa	North America	Low-income	Lower-middle-income	Upper-middle-income	High-income
Trend	0.01	0.001	0.03	0.02	-0.02	-0.02	0.01	-0.03	0.03	0.01	0.01
t-statistic	1.77	2.01	4.71	2.94	-1.32	-1.90	4.69	-5.15	5.97	1.46	3.37
Constant	2.52	2.86	0.72	2.77	1.78	2.46	3.08	2.77	2.47	2.60	2.63
	21.65	62.30	3.90	11.19	5.22	9.45	57.34	16.16	20.87	24.86	57.77
R^2 Within	0.01	0.001	0.13	0.13	0.03	0.03	0.22	0.09	0.10	0.01	0.01
R^2 Between	0.001	0.01	0.001	0.63	0.50	0.45	0.90	0.10	0.01	0.15	0.01
R^2 Overall	0.01	0.001	0.05	0.19	0.001	0.001	0.03	0.001	0.02	0.02	0.001
F test	3.14	4.03	22.16	8.62	1.75	3.62	22.03	26.57	35.66	2.14	11.38
Number of obs	363	980	157	61	58	121	80	285	323	296	916

Table 3.2: Trends in the use of gas as source of energy production for industrial uses in World Bank macroareas and per capita income subgroups

Ln(GAS)	East Asia and Pacific	Europe and Central Asia	Latin America and the Caribbean	Middle East and North Africa	South Asia	Sub-Saharan Africa	North America	Low-income	Lower-middle-income	Upper-middle-income	High-income
Trend	0.13	0.04	0.02	0.01	0.04	0.03	-0.01	0.06	0.04	0.00	0.05
t-statistic	17.97	9.59	5.07	4.26	6.94	2.68	-5.27	8.62	11.26	0.50	13.79
Constant	-1.60	0.58	1.51	3.39	1.60	0.97	2.24	0.79	1.32	2.04	0.59
	-7.81	5.04	11.16	36.96	9.96	2.66	34.24	4.02	11.70	15.89	5.69
R^2 Within	0.54	0.11	0.10	0.06	0.37	0.09	0.27	0.22	0.26	0.00	0.19
R^2 Between	0.04	0.02	0.83	0.26	0.33	0.01	1.00	0.00	0.10	0.01	0.10
R^2 Overall	0.17	0.05	0.01	0.00	0.04	0.02	0.04	0.02	0.00	0.01	0.03
F test	322.97	91.91	25.75	18.16	48.10	7.20	27.81	74.35	126.71	0.25	190.09
Number of obs	290	815	248	310	87	76	80	286	387	400	833

Table 3.3: Trends in the use of oil as source of energy production for industrial uses in World Bank macroareas and per capita income subgroups

Ln(OIL)	East Asia and Pacific	Europe and Central Asia	Latin America and the Caribbean	Middle East and North Africa	South Asia	Sub-Saharan Africa	North America	Low-income	Lower-middle-income	Upper-middle-income	High-income
Trend	-0.06	-0.05	-0.05	-0.01	-0.01	-0.05	-0.01	-0.05	-0.04	-0.04	-0.04
t-statistic	-15.04	-19.91	-11.40	-4.27	-1.35	-12.79	-2.69	-14.21	-12.85	-13.94	-17.21
Constant	4.18	3.36	3.94	4.04	2.38	3.69	1.67	4.01	3.98	3.90	3.03
	39.24	55.03	36.44	47.84	8.80	31.34	15.07	41.31	45.61	45.46	51.70
R^2 Within	0.36	0.25	0.17	0.04	0.01	0.25	0.09	0.20	0.16	0.24	0.20
R^2 Between	0.09	0.06	0.21	0.02	0.00	0.00	0.50	0.05	0.04	0.11	0.02
R^2 Overall	0.05	0.03	0.04	0.01	0.01	0.04	0.04	0.04	0.04	0.02	0.03
F test	226.13	396.47	130.02	18.25	1.81	163.48	7.23	201.82	165.11	194.39	296.20
Number of obs	419	1257	661	507	138	511	80	847	891	650	1185

Table 3.4: World Bank macroareas and per capita income subgroups mean values of using carbon, gas and oil source of energy production for industrial uses

	East Asia and Pacific	Europe and Central Asia	Latin America and the Caribbean	Middle East and North Africa	South Asia	Sub-Saharan Africa	North America	Low-income	Lower-middle-income	Upper-middle-income	High-income
1971											
COAL	27.99	38.27	5.86	13.41	26.07	50.93	31.79	30.53	37.16	41.43	26.89
GAS	21.48	13.33	28.05	62.16	28.34	7.06	13.32	17.18	22.17	22.89	31.57
OIL	49.17	28.39	41.76	70.39	16.26	43.04	8.36	39.70	46.28	47.72	37.27
1999											
COAL	33.73	31.42	11.10	58.47	38.00	50.72	35.35	23.30	40.39	30.51	31.99
GAS	34.85	23.33	27.67	59.73	39.93	23.75	10.11	33.59	36.98	27.61	28.16
OIL	16.31	11.65	36.33	51.26	17.53	26.51	2.85	29.00	26.63	26.75	18.41

Table 4.1: Panel Unit Root Test by Im, Pesaran and Shin (2003)

		Ln (CO_2 per unit of GDP)	Ln(GDPPC)	Ln(COAL)	Ln(GAS)	Ln(OIL)	Ln(TRACTOR)	Ln(FERT)	Ln(POP)	Ln(RADIO)	Ln(TELEPH)	Ln(FIMP)
Fixed effects	***t-bar***	-1.67	-1.21	-1.65	-1.68	-1.60	-1.76	-1.68	-1.25	-1.75	-0.53	-1.85
	Critical Value 10%	-1.64	-1.64	-1.69	-1.69	-1.64	-1.64	-1.64	-1.64	-1.64	-1.64	-1.64
	Critical Value 5%	-1.67	-1.67	-1.73	-1.73	-1.67	-1.67	-1.67	-1.67	-1.67	-1.67	-1.67
	Critical Value 1%	-1.73	-1.73	-1.82	-1.82	-1.73	-1.73	-1.73	-1.73	-1.73	-1.73	-1.73
	W-bar	-1.74	3.62	-0.99	-1.15	-0.92	-3.29	-2.06	3.71	-2.47	12.40	-2.853
	p-value	0.04	1.00	0.16	0.12	0.18	0.00	0.02	1.00	0.01	1.00	0.002
	N	114	119	44	41	97	158	126	165	93	137	62
Fixed effects and Time trends	***t-bar***	-2.36	-1.96	-2.33	-1.89	-2.02	-2.04	-2.44	-2.08	-2.10	-1.38	-2.53
	Critical Value 10%	-2.28	-2.28	-2.33	-2.33	-2.28	-2.28	-2.28	-2.28	-2.28	-2.28	-2.28
	Critical Value 5%	-2.31	-2.31	-2.37	-2.37	-2.31	-2.31	-2.31	-2.31	-2.31	-2.31	-2.31
	Critical Value 1%	-2.37	-2.37	-2.45	-2.45	-2.37	-2.37	-2.37	-2.37	-2.37	-2.37	-2.37
	W-bar	-2.32	2.64	-1.20	2.04	1.75	1.94	-3.37	1.39	0.75	10.64	-3.175
	p-value	0.01	1.00	0.12	0.98	0.96	0.97	0.00	0.92	0.77	1.00	0.001
	N	114	119	44	41	97	158	126	165	93	137	62

The null hypothesis of the test is existence of unit root (H_0: ρ_i=1) against the alternative no presence of unit root (H1: ρ_i <1 for each i=1,…,N_1 and ρ_i =1 for each i=N_1+1,…,N for some N_1)

Table 4.2: Panel Cointegration Test by Nyblom and Harvey (2000)

		Ln (CO_2 per unit of GDP)	Ln(GDPPC)	Ln(COAL)	Ln(GAS)	Ln(OIL)	Ln(TRACTOR)	Ln(FERT)	Ln(POP)	Ln(RADIO)	Ln(TELEPH)	Ln(FIMP)
Fixed effects	***NH-t***	11.48	11.48	11.48	11.48	11.48	11.48	11.48	11.48	11.48	11.48	11.48
	NH adj-t	107.48	107.48	107.48	107.48	107.48	107.48	107.48	107.48	107.48	107.48	107.48
	Critical Value 10%	CV>18.36	CV>18.36	7.86<CV<9.57	7.86<CV<9.57	14.02<CV<18.36	CV>18.36	CV>18.36	CV>18.36	14.02<CV<18.36	CV>18.36	9.57<CV<14.01
	Critical Value 5%	CV>19.01	CV>19.01	8.26<CV<10.03	8.26<CV<10.03	14.60<CV<19.01	CV>19.01	CV>19.01	CV>19.01	14.60<CV<19.01	CV>19.01	10.03<CV<14.60
	Critical Value 1%	CV>20.25	CV>20.25	9.02<CV<10.92	9.02<CV<10.92	15.69<CV<20.25	CV>20.25	CV>20.25	CV>20.25	15.69<CV<20.25	CV>20.25	10.92<CV<15.69
	N	N>100	N>100	40<N<50	40<N<50	75<N<100	N>100	N>100	N>100	75<N<100	N>100	50<N<75
Fixed effects and Time trends	***NH-t***	10.96	10.96	10.96	10.96	10.96	10.96	10.96	10.96	10.96	10.96	10.96
	NH adj-t	106.37	106.37	106.37	106.37	106.37	106.37	106.37	106.37	106.37	106.37	106.37
	Critical Value 10%	CV>7.21	CV>7.21	3.01<CV<3.72	3.01<CV<3.72	5.47<CV<7.21	CV>7.21	CV>7.21	CV>7.21	5.47<CV<7.21	CV>7.21	3.72<CV<5.47
	Critical Value 5%	CV>7.37	CV>7.37	3.13<CV<3.85	3.13<CV<3.85	5.62<CV<7.37	CV>7.37	CV>7.37	CV>7.37	5.62<CV<7.37	CV>7.37	3.85<CV<5.62
	Critical Value 1%	CV>7.69	CV>7.69	3.34<CV<4.09	3.34<CV<4.09	5.91<CV<7.69	CV>7.69	CV>7.69	CV>7.69	5.91<CV<7.69	CV>7.69	4.09<CV<5.91
	N	N>100	N>100	40<N<50	40<N<50	75<N<100	N>100	N>100	N>100	75<N<100	N>100	50<N<75

The null hypothesis of the test is no cointegration (H0: rank(var-cov)=K=0) against the alternative hypothesis of cointegration (H1: rank(var-cov)=K $\neq$ 0)

NH-t: the test is performed under the hypothesis of iid errors. Nh ADJ-T: errors are allowed to be serially correlated and the test is performed using an estimate of the long-run variance derived from the spectral density matrix at frequency zero.

Table 5. Fixed effect estimates of unadjusted and adjusted EKC specifications

	NON CONSTANT NUMBER OF OBSERVATIONS		CONSTANT NUMBER OF OBSERVATIONS	
Dep. Variable: Ln (CO_2 per unit of GDP)	EKC unadjusted	adjusted EKC (unadjusted EKC + energy + agriculture+ population+ social variable+ fuel)	EKC unadjusted	adjusted EKC (unadjusted EKC + energy + agriculture+ population+ social variable+ fuel)
Ln(GDPPC)	1.116+++	1.708+++	1.977+++	1.818+++
t-statistic	[10.63]	[8.57]	[12.66]	[8.73]
Ln(GDPPC)^2	-0.067+++	-0.117+++	-0.141+++	-0.123+++
t-statistic	[-10.34]	[-11.39]	[-15.38]	[-11.49]
Ln(COAL)		0.036+++		0.045+++
t-statistic		[5.29]		[5.41]
Ln(GAS)		0.02+++		0.02+++
t-statistic		[4.66]		[3.37]
Ln(OIL)		0.02+++		0.02++
t-statistic		[3.45]		[2.38]
Ln(TRACTOR)		0.16+++		0.16+++
t-statistic		[8.41]		[8.26]
Ln(FERT)		0.05+++		0.05+++
t-statistic		[3.31]		[3.13]
Ln(POP)		0.450+++		0.433+++
t-statistic		[5.54]		[5.15]
Ln(RADIO)		-0.044+++		-0.043+++
t-statistic		[-3.92]		[-3.78]
Ln(TELEPH)		-0.182+++		-0.188+++
t-statistic		[-8.19]		[-8.21]
Ln(FUELIMP)		-0.017		-0.019+
t-statistic		[-1.55]		[-1.63]
Constant	-4.837+++	-5.596+++	-6.504+++	-5.907+++
t-statistic	[-11.59]	[-5.51]	[-9.66]	[-5.57]
R-sq Within	0.02	0.63	0.43	0.63
R-sq Between	0.01	0.16	0.59	0.15
R-sq Overall	0.01	0.16	0.55	0.16
F test *	56.73+++	90.80+++	213.38+++	84.82+++
F test (u_i =0) **	147.59+++	160.79+++	233.31+++	149.39+++
Hausman χ^2 ***	9.09+++	88.98+++	9.18+++	68.35+++
Number of obs	4979	653	611	611
EKC maximum****	4139.62	1460.24	1108.36	1572.71

F test *: Ho: joint significance of the regressors; F test **: Ho. Joint significance of the fixed effects. Hausman χ^2 ***: Ho: random effects may be used alternatively to fixed effects. **** thousands of 1995 dollars. +++ coeff. signif. at 1%; ++ coeff. signif. at 5% and + coeff. signif. at 10% Variable legend: see Table 1.

Table 6.1: Rolling fixed effect estimation of unadjusted EKC - 20 years sample intervals. Dependent Variable: Ln(CO_2 per unit of GDP)

	<1980	1961-1980	1962-1981	1963-1982	1964-1983	1965-1984	1966-1985	1967-1986	1968-1987	1969-1988	1970-1989	1971-1990	1972-1991	1973-1992	1974-1993	1975-1994	1976-1995	1977-1996	1978-1997	1979-1998	1980-1999	1981-2000	1982-2001
Ln(GDPPC)	1.823	1.638	1.544	1.467	1.475	1.427	1.400	1.410	1.332	1.254	1.237	1.247	1.246	1.093	0.959	0.874	0.758	0.638	0.554	0.491	0.446	0.361	0.244
t-statistic	[8.03]	[7.39]	[7.05]	[6.78]	[6.93]	[6.88]	[7.01]	[7.48]	[7.21]	[6.99]	[7.00]	[7.30]	[7.35]	[6.60]	[6.00]	[5.73]	[5.10]	[4.40]	[3.93]	[3.62]	[3.20]	[2.51]	[1.63]
Ln(GDPPC)^2	-0.078	-0.070	-0.069	-0.067	-0.071	-0.074	-0.079	-0.088	-0.090	-0.089	-0.093	-0.096	-0.097	-0.089	-0.082	-0.077	-0.069	-0.060	-0.052	-0.046	-0.041	-0.035	-0.027
t-statistic	[-5.53]	[-5.11]	[-5.04]	[-4.99]	[-5.35]	[-5.69]	[-6.32]	[-7.46]	[-7.70]	[-7.92]	[-8.35]	[-8.92]	[-9.07]	[-8.51]	[-8.10]	[-7.93]	[-7.29]	[-6.43]	[-5.77]	[-5.26]	[-4.56]	[-3.74]	[-2.76]
Constant	-9.626	-8.671	-8.048	-7.537	-7.356	-6.822	-6.293	-5.815	-5.141	-4.552	-4.215	-4.103	-4.029	-3.328	-2.727	-2.377	-1.962	-1.600	-1.403	-1.298	-1.252	-0.978	-0.568
	[-10.73]	[-9.92]	[-9.33]	[-8.85]	[-8.79]	[-8.38]	[-8.02]	[-7.85]	[-7.08]	[-6.45]	[-6.06]	[-6.11]	[-6.06]	[-5.11]	[-4.36]	[-3.98]	[-3.38]	[-2.83]	[-2.56]	[-2.47]	[-2.33]	[-1.77]	[-0.99]
R^2 Within	0.13	0.11	0.09	0.07	0.06	0.04	0.03	0.02	0.03	0.03	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.04	0.03	0.02	0.02	0.02
R^2 Between	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.02	0.02	0.03	0.05	0.06	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06
R^2 Overall	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.05	0.05	0.06	0.06	0.06	0.05
F test *	149.41	122.49	96.63	78.36	65.66	45.56	30.50	28.13	31.85	41.35	57.20	72.23	77.67	82.45	88.49	91.15	83.84	69.88	56.04	44.24	31.09	24.36	18.90
F test (u_i =0) **	109.12	101.93	98.19	100.09	105.13	109.21	115.51	128.92	134.38	143.66	150.14	160.86	161.67	153.40	165.81	180.37	192.64	205.35	219.68	236.01	242.43	247.04	248.82
N. of obs.	2074	2119	2168	2216	2263	2309	2354	2400	2446	2493	2540	2582	2626	2687	2747	2807	2865	2922	2974	3024	2903	2773	2638
EKC maximum	119418.83	113104.05	75623.94	52823.65	30953.38	15390.13	6830.83	2919.06	1694.42	1109.82	783.57	668.45	620.19	463.50	349.37	295.24	243.59	208.59	199.99	207.09	227.16	175.46	92.77

Table 6.2: Rolling fixed effect estimation of unadjusted EKC- 20 years sample intervals (constant number of countries) Dependent Variable: Ln (CO_2 per unit of GDP)

	<1980	1961-1980	1962-1981	1963-1982	1964-1983	1965-1984	1966-1985	1967-1986	1968-1987	1969-1988	1970-1989	1971-1990	1972-1991	1973-1992	1974-1993	1975-1994	1976-1995	1977-1996	1978-1997	1979-1998	1980-1999	1981-2000	1982-2001
Ln(GDPPC)	-0.234	0.132	0.807	1.465	2.060	1.930	2.134	2.151	2.243	2.226	2.216	2.388	2.362	2.339	2.298	2.221	2.099	1.899	1.701	1.566	1.429	1.191	0.972
t-statistic	[-0.38]	[0.26]	[1.71]	[2.80]	[4.33]	[4.10]	[5.28]	[5.90]	[6.84]	[7.68]	[8.47]	[9.70]	[10.40]	[11.11]	[11.61]	[11.89]	[11.29]	[10.65]	[9.78]	[8.83]	[7.90]	[6.47]	[5.07]
Ln(GDPPC)^2	-0.019	-0.040	-0.079	-0.117	-0.154	-0.151	-0.164	-0.166	-0.171	-0.170	-0.167	-0.175	-0.170	-0.167	-0.163	-0.157	-0.148	-0.132	-0.117	-0.108	-0.097	-0.080	-0.066
t-statistic	[-0.56]	[-1.46]	[-3.02]	[-4.04]	[-5.78]	[-5.74]	[-7.25]	[-8.11]	[-9.28]	[-10.38]	[-11.36]	[-12.33]	[-12.95]	[-13.62]	[-14.05]	[-14.28]	[-13.28]	[-12.21]	[-11.14]	[-10.03]	[-8.86]	[-7.14]	[-5.65]
Constant	3.347	1.801	-1.087	-3.840	-6.182	-5.236	-6.059	-6.057	-6.434	-6.408	-6.513	-7.432	-7.583	-7.622	-7.559	-7.332	-7.018	-6.548	-5.912	-5.475	-5.103	-4.362	-3.551
t-statistic	[1.20]	[0.78]	[-0.51]	[-1.64]	[-2.92]	[-2.50]	[-3.35]	[-3.72]	[-4.41]	[-4.98]	[-5.59]	[-6.89]	[-7.65]	[-8.34]	[-8.87]	[-9.17]	[-8.96]	[-8.78]	[-8.17]	[-7.45]	[-6.82]	[-5.78]	[-4.52]
R^2 within	0.55	0.58	0.54	0.46	0.48	0.50	0.54	0.55	0.56	0.58	0.59	0.52	0.50	0.48	0.46	0.44	0.37	0.30	0.25	0.21	0.18	0.12	0.09
R^2 between	0.46	0.47	0.50	0.47	0.43	0.47	0.52	0.54	0.53	0.52	0.53	0.48	0.49	0.51	0.51	0.53	0.54	0.54	0.56	0.56	0.55	0.53	0.55
R^2 overall	0.41	0.44	0.48	0.48	0.47	0.49	0.50	0.51	0.52	0.53	0.53	0.52	0.50	0.50	0.51	0.52	0.52	0.51	0.53	0.53	0.51	0.49	0.52
F test *	39.68	58.88	59.55	50.40	62.49	74.08	101.28	118.13	139.26	162.66	188.45	155.57	156.98	162.87	164.44	164.91	131.45	101.12	82.70	66.58	50.25	30.84	20.39
F test (u_i =0) **	332.73	376.67	301.23	220.44	216.17	210.06	201.62	194.70	204.67	212.93	212.71	205.37	218.94	225.11	224.32	215.28	218.05	236.59	238.10	247.18	260.56	279.16	283.90
N. of obs.	88	107	125	142	160	173	198	221	245	269	298	318	352	387	422	462	486	516	547	538	523	504	486
EKC maximum	0.002	5.19	166.56	515.91	809.58	589.98	680.03	661.11	702.97	707.00	752.95	923.19	1039.41	1100.98	1141.58	1153.27	1209.63	1367.97	1401.08	1418.79	1534.64	1663.41	1529.53

EKC maximum is measured in thousands of 1995 dollars.

Table 7.1: Rolling fixed effect estimation of the adjusted EKC - 20 years sample intervals. Dependent Variable: Ln (CO_2 per unit of GDP)

	<1980	1961-1980	1962-1981	1963-1982	1964-1983	1965-1984	1966-1985	1967-1986	1968-1987	1969-1988	1970-1989	1971-1990	1972-1991	1973-1992	1974-1993	1975-1994	1976-1995	1977-1996	1978-1997	1979-1998	1980-1999	1981-2000	1982-2001
Ln(GDPPC)	0.419	0.134	-0.111	0.168	1.000	0.840	1.018	1.211	1.716	1.906	1.946	2.158	2.165	2.111	2.091	2.048	2.123	1.805	1.368	1.134	0.960	0.784	0.484
t-statistic	[0.60]	[0.25]	[-0.23]	[0.29]	[1.93]	[1.78]	[2.52]	[3.22]	[4.98]	[6.17]	[6.75]	[7.37]	[7.64]	[7.85]	[8.11]	[8.19]	[8.45]	[7.29]	[5.73]	[4.69]	[3.96]	[3.17]	[1.86]
$Ln(GDPPC)^2$	-0.080	-0.061	-0.047	-0.059	-0.099	-0.091	-0.097	-0.107	-0.134	-0.143	-0.145	-0.152	-0.149	-0.144	-0.142	-0.139	-0.140	-0.116	-0.091	-0.076	-0.064	-0.053	-0.036
t-statistic	[-1.99]	[-2.01]	[-1.73]	[-1.81]	[-3.41]	[-3.40]	[-4.26]	[-5.08]	[-6.99]	[-8.45]	[-9.20]	[-9.50]	[-9.71]	[-9.97]	[-10.27]	[-10.48]	[-10.39]	[-8.69]	[-7.02]	[-5.76]	[-4.83]	[-3.93]	[-2.57]
Ln(COAL)	0.038	0.042	-0.010	0.003	0.008	0.007	0.010	0.007	0.015	0.020	0.024	0.045	0.045	0.048	0.046	0.042	0.041	0.038	0.036	0.033	0.030	0.025	0.028
t-statistic	[1.48]	[2.11]	[-0.66]	[0.27]	[0.68]	[0.61]	[0.94]	[0.73]	[1.59]	[2.16]	[2.68]	[4.93]	[5.27]	[5.81]	[6.01]	[5.86]	[5.96]	[5.35]	[4.96]	[4.51]	[4.14]	[3.61]	[3.59]
Ln(GAS)	0.034	0.034	0.036	0.041	0.042	0.041	0.044	0.044	0.046	0.048	0.048	0.034	0.034	0.033	0.029	0.023	0.013	0.013	0.009	0.007	0.003	-0.002	-0.005
t-statistic	[5.21]	[5.74]	[5.90]	[5.53]	[5.45]	[5.36]	[6.04]	[6.24]	[6.63]	[6.97]	[7.00]	[4.01]	[4.17]	[4.16]	[3.91]	[3.39]	[1.97]	[2.06]	[1.54]	[1.17]	[0.56]	[-0.34]	[-0.94]
Ln(OIL)	0.034	0.023	0.040	0.043	0.050	0.054	0.052	0.048	0.041	0.034	0.027	0.019	0.020	0.023	0.021	0.021	0.023	0.028	0.031	0.029	0.025	0.014	0.009
t-statistic	[2.49]	[2.31]	[4.66]	[4.58]	[5.30]	[5.96]	[6.31]	[5.88]	[5.09]	[4.42]	[3.58]	[2.52]	[2.80]	[3.26]	[3.17]	[3.29]	[3.60]	[4.23]	[4.59]	[4.08]	[3.47]	[1.83]	[1.13]
Ln(FERTIZER)	0.046	0.047	0.059	0.075	0.081	0.093	0.085	0.079	0.071	0.078	0.074	0.111	0.091	0.098	0.114	0.129	0.158	0.159	0.190	0.195	0.209	0.223	0.237
t-statistic	[1.20]	[1.49]	[1.87]	[1.99]	[2.13]	[2.44]	[2.47]	[2.36]	[2.16]	[2.46]	[2.41]	[3.20]	[2.84]	[3.35]	[4.25]	[5.19]	[6.48]	[6.88]	[8.79]	[9.00]	[9.87]	[10.68]	[11.11]
Ln(TRACT)	0.091	0.094	0.137	0.166	0.106	0.080	0.016	-0.045	-0.086	-0.092	-0.082	-0.027	0.000	0.021	0.030	0.048	0.059	0.060	0.073	0.067	0.062	0.057	0.055
t-statistic	[1.88]	[2.28]	[3.48]	[3.47]	[2.24]	[1.74]	[0.40]	[-1.20]	[-2.50]	[-2.92]	[-2.68]	[-0.96]	[0.02]	[1.02]	[1.56]	[2.58]	[3.36]	[3.61]	[4.62]	[4.33]	[4.11]	[3.75]	[3.56]
Ln(POP)	0.782	0.688	0.621	0.504	0.275	0.369	0.386	0.395	0.289	0.278	0.342	0.500	0.468	0.455	0.470	0.422	0.386	0.426	0.494	0.576	0.651	0.679	0.729
t-statistic	[2.71]	[2.90]	[2.75]	[2.05]	[1.25]	[1.85]	[2.27]	[2.47]	[1.94]	[2.02]	[2.66]	[3.74]	[3.75]	[3.87]	[4.22]	[4.14]	[3.80]	[4.17]	[4.93]	[5.59]	[6.29]	[6.50]	[6.71]
Ln(RADIO)	0.000	-0.002	-0.002	-0.004	-0.007	-0.009	-0.010	-0.010	-0.009	-0.008	-0.011	-0.203	-0.187	-0.174	-0.168	-0.112	-0.116	-0.103	-0.085	-0.076	-0.061	-0.053	-0.042
t-statistic	[-0.05]	[-0.23]	[-0.27]	[-0.42]	[-0.69]	[-0.85]	[-0.98]	[-0.93]	[-0.82]	[-0.77]	[-0.95]	[-4.55]	[-4.83]	[-5.14]	[-5.47]	[-4.71]	[-5.11]	[-4.64]	[-3.89]	[-3.48]	[-2.84]	[-2.51]	[-1.99]
Ln(TELEPH)	0.106	0.085	0.052	-0.005	-0.039	-0.062	-0.068	-0.071	-0.064	-0.088	-0.113	-0.135	-0.145	-0.159	-0.171	-0.188	-0.201	-0.186	-0.172	-0.165	-0.164	-0.156	-0.144
t-statistic	[1.82]	[1.83]	[1.19]	[-0.11]	[-0.79]	[-1.29]	[-1.56]	[-1.66]	[-1.55]	[-2.22]	[-2.94]	[-3.12]	[-3.71]	[-4.46]	[-5.28]	[-6.28]	[-7.15]	[-7.04]	[-6.97]	[-6.65]	[-6.66]	[-6.27]	[-5.66]
Ln(FUELIMP)	-0.036	-0.031	-0.043	-0.045	-0.024	-0.017	-0.023	-0.021	-0.017	-0.019	-0.022	-0.043	-0.045	-0.045	-0.044	-0.045	-0.047	-0.024	-0.005	0.010	0.022	0.027	0.033
t-statistic	[-1.76]	[-1.70]	[-2.56]	[-2.32]	[-1.27]	[-0.88]	[-1.31]	[-1.43]	[-1.32]	[-1.64]	[-1.89]	[-3.35]	[-3.53]	[-3.63]	[-3.65]	[-3.72]	[-3.56]	[-1.70]	[-0.39]	[0.69]	[1.58]	[2.00]	[2.45]
Constant	-0.224	1.369	3.378	2.880	-0.817	-0.501	-2.304	-3.893	-6.282	-7.073	-7.374	-7.252	-7.313	-6.968	-6.831	-6.434	-6.502	-5.931	-4.339	-3.936	-3.747	-3.244	-2.228
t-statistic	[-0.06]	[0.49]	[1.46]	[1.06]	[-0.34]	[-0.22]	[-1.20]	[-2.17]	[-3.78]	[-4.65]	[-5.07]	[-4.97]	[-5.14]	[-5.15]	[-5.27]	[-5.10]	[-5.24]	[-4.92]	[-3.75]	[-3.38]	[-3.18]	[-2.66]	[-1.75]
R^2 within	0.68	0.71	0.71	0.62	0.62	0.65	0.69	0.69	0.69	0.70	0.70	0.67	0.65	0.65	0.65	0.63	0.61	0.55	0.53	0.50	0.49	0.45	0.43
R^2 between	0.09	0.12	0.18	0.20	0.32	0.31	0.39	0.44	0.53	0.54	0.50	0.38	0.35	0.33	0.30	0.33	0.19	0.05	0.03	0.01	0.00	0.00	0.00
R^2 overall	0.06	0.09	0.11	0.14	0.28	0.26	0.30	0.35	0.46	0.48	0.44	0.30	0.28	0.26	0.24	0.26	0.22	0.10	0.04	0.02	0.01	0.00	0.00
F test *	12.33	18.82	22.67	18.23	20.82	26.23	36.31	40.23	45.57	53.77	59.70	56.18	57.41	62.91	67.06	69.18	65.29	55.52	54.35	47.40	42.73	35.18	31.74
F test (u_i =0) **	156.43	193.69	172.78	119.26	112.71	116.31	119.88	120.62	125.98	138.15	139.60	116.74	122.25	128.02	131.74	135.69	138.45	137.55	137.01	140.60	148.32	155.88	155.06
N. of obs.	96	117	137	156	176	191	218	243	269	295	326	347	383	420	457	499	524	554	585	574	557	536	516
EKC maximum	13.92	2.98	0.31	4.19	155.75	98.93	185.44	284.79	603.66	769.44	836.79	1198.13	1434.88	1528.73	1613.60	1570.70	1951.09	2313.59	1877.78	1728.14	1788.05	1632.60	779.19

Table 7.2: Rolling fixed effect estimation of the adjusted EKC - 20 years sample intervals (constant number of countries). Dependent Variable: Ln **(CO_2 per unit of GDP)**

	<1980	1961-1980	1962-1981	1963-1982	1964-1983	1965-1984	1966-1985	1967-1986	1968-1987	1969-1988	1970-1989	1971-1990	1972-1991	1973-1992	1974-1993	1975-1994	1976-1995	1977-1996	1978-1997	1979-1998	1980-1999	1981-2000	1982-2001
Ln(GDPPC)	-0.103	-0.170	-0.356	-0.016	0.897	0.786	0.999	1.248	1.776	1.972	2.000	2.164	2.200	2.172	2.185	2.157	2.232	1.888	1.434	1.197	1.017	0.825	0.529
t-statistic	[-0.16]	[-0.33]	[-0.75]	[-0.03]	[1.68]	[1.62]	[2.39]	[3.21]	[4.97]	[6.15]	[6.70]	[7.08]	[7.38]	[7.68]	[8.06]	[8.22]	[8.54]	[7.32]	[5.81]	[4.81]	[4.08]	[3.26]	[1.98]
$Ln(GDPPC)^2$	-0.050	-0.044	-0.034	-0.048	-0.093	-0.088	-0.096	-0.109	-0.137	-0.147	-0.148	-0.153	-0.152	-0.148	-0.148	-0.146	-0.147	-0.122	-0.095	-0.080	-0.068	-0.056	-0.040
t-statistic	[-1.36]	[-1.51]	[-1.25]	[-1.42]	[-3.08]	[-3.15]	[-4.04]	[-5.00]	[-6.91]	[-8.35]	[-9.07]	[-9.19]	[-9.42]	[-9.77]	[-10.20]	[-10.49]	[-10.49]	[-8.73]	[-7.09]	[-5.89]	[-4.96]	[-4.03]	[-2.72]
Ln(COAL)	0.039	0.037	-0.029	-0.002	0.004	0.004	0.007	0.007	0.017	0.022	0.026	0.049	0.050	0.054	0.056	0.055	0.057	0.052	0.049	0.045	0.040	0.034	0.042
t-statistic	[1.55]	[1.74]	[-1.68]	[-0.14]	[0.32]	[0.30]	[0.67]	[0.66]	[1.63]	[2.27]	[2.72]	[5.05]	[5.35]	[5.91]	[6.29]	[6.26]	[6.41]	[5.67]	[5.28]	[4.75]	[4.26]	[3.66]	[3.78]
Ln(GAS)	0.016	0.017	0.019	0.027	0.029	0.029	0.034	0.036	0.040	0.041	0.041	0.032	0.032	0.031	0.026	0.019	0.008	0.009	0.006	0.004	0.000	-0.005	-0.008
t-statistic	[2.08]	[2.38]	[2.58]	[2.82]	[2.98]	[3.00]	[3.78]	[4.21]	[4.72]	[5.02]	[5.16]	[3.52]	[3.65]	[3.64]	[3.26]	[2.68]	[1.20]	[1.41]	[0.93]	[0.61]	[0.01]	[-0.87]	[-1.32]
Ln(OIL)	0.025	0.019	0.043	0.042	0.049	0.053	0.053	0.047	0.038	0.030	0.023	0.014	0.015	0.017	0.015	0.015	0.017	0.022	0.025	0.024	0.020	0.008	0.002
t-statistic	[1.92]	[1.83]	[4.74]	[4.07]	[4.79]	[5.39]	[5.75]	[5.18]	[4.30]	[3.61]	[2.87]	[1.70]	[1.89]	[2.22]	[2.03]	[2.12]	[2.42]	[3.20]	[3.57]	[3.19]	[2.55]	[0.94]	[0.24]
Ln(FERT)	0.024	0.032	0.043	0.062	0.070	0.083	0.076	0.076	0.073	0.082	0.076	0.129	0.105	0.110	0.127	0.141	0.171	0.168	0.197	0.200	0.214	0.228	0.241
t-statistic	[0.69]	[1.09]	[1.42]	[1.61]	[1.77]	[2.09]	[2.13]	[2.15]	[2.10]	[2.45]	[2.36]	[3.43]	[3.04]	[3.51]	[4.46]	[5.37]	[6.70]	[7.00]	[8.83]	[9.00]	[9.88]	[10.72]	[11.09]
Ln(TRACTOR)	0.086	0.086	0.143	0.164	0.105	0.079	0.012	-0.046	-0.088	-0.093	-0.085	-0.024	0.005	0.026	0.036	0.054	0.065	0.064	0.076	0.069	0.065	0.060	0.056
t-statistic	[1.92]	[2.16]	[3.63]	[3.28]	[2.11]	[1.65]	[0.30]	[-1.19]	[-2.43]	[-2.82]	[-2.66]	[-0.81]	[0.21]	[1.22]	[1.79]	[2.81]	[3.60]	[3.75]	[4.67]	[4.38]	[4.17]	[3.85]	[3.60]
Ln(POP)	0.965	0.856	0.714	0.613	0.371	0.445	0.450	0.427	0.302	0.283	0.360	0.488	0.454	0.438	0.439	0.384	0.342	0.382	0.452	0.530	0.605	0.632	0.676
t-statistic	[3.61]	[3.76]	[3.21]	[2.43]	[1.62]	[2.15]	[2.53]	[2.56]	[1.94]	[1.98]	[2.70]	[3.53]	[3.51]	[3.59]	[3.80]	[3.65]	[3.25]	[3.58]	[4.32]	[4.92]	[5.58]	[5.75]	[5.93]
Ln(RADIO)	-0.004	-0.005	-0.004	-0.006	-0.009	-0.010	-0.011	-0.010	-0.009	-0.008	-0.010	-0.215	-0.193	-0.176	-0.172	-0.116	-0.121	-0.106	-0.087	-0.077	-0.062	-0.053	-0.042
t-statistic	[-0.63]	[-0.69]	[-0.59]	[-0.61]	[-0.79]	[-0.92]	[-0.99]	[-0.88]	[-0.76]	[-0.71]	[-0.90]	[-4.53]	[-4.73]	[-5.01]	[-5.42]	[-4.78]	[-5.21]	[-4.65]	[-3.89]	[-3.47]	[-2.83]	[-2.49]	[-1.94]
Ln(TELEPH)	0.077	0.061	0.024	-0.033	-0.063	-0.082	-0.083	-0.081	-0.073	-0.098	-0.123	-0.131	-0.147	-0.163	-0.174	-0.190	-0.202	-0.186	-0.173	-0.164	-0.164	-0.155	-0.143
t-statistic	[1.41]	[1.32]	[0.53]	[-0.61]	[-1.17]	[-1.56]	[-1.76]	[-1.77]	[-1.63]	[-2.29]	[-3.03]	[-2.86]	[-3.56]	[-4.37]	[-5.16]	[-6.11]	[-6.97]	[-6.86]	[-6.83]	[-6.49]	[-6.51]	[-6.11]	[-5.51]
Ln(FUELIMP)	-0.029	-0.027	-0.037	-0.044	-0.024	-0.016	-0.023	-0.021	-0.018	-0.019	-0.022	-0.043	-0.045	-0.045	-0.045	-0.047	-0.050	-0.028	-0.010	0.005	0.016	0.021	0.028
t-statistic	[-1.56]	[-1.54]	[-2.30]	[-2.22]	[-1.21]	[-0.80]	[-1.27]	[-1.40]	[-1.27]	[-1.52]	[-1.76]	[-3.13]	[-3.32]	[-3.40]	[-3.49]	[-3.63]	[-3.60]	[-1.88]	[-0.67]	[0.31]	[1.13]	[1.50]	[1.99]
Constant	1.419	2.112	4.321	3.326	-0.679	-0.480	-2.444	-4.108	-6.505	-7.285	-7.607	-6.924	-7.126	-6.896	-6.837	-6.483	-6.515	-5.881	-4.264	-3.847	-3.621	-3.038	-2.048
t-statistic	[0.44]	[0.80]	[1.91]	[1.20]	[-0.27]	[-0.21]	[-1.24]	[-2.22]	[-3.77]	[-4.60]	[-5.03]	[-4.51]	[-4.74]	[-4.84]	[-5.03]	[-4.91]	[-5.06]	[-4.71]	[-3.57]	[-3.21]	[-2.99]	[-2.44]	[-1.58]
R^2 within	0.74	0.75	0.74	0.63	0.63	0.66	0.69	0.69	0.69	0.70	0.70	0.67	0.65	0.65	0.64	0.63	0.61	0.55	0.53	0.50	0.48	0.45	0.44
R^2 between	0.08	0.10	0.18	0.18	0.24	0.25	0.34	0.40	0.49	0.50	0.46	0.36	0.34	0.31	0.30	0.32	0.20	0.06	0.04	0.02	0.00	0.00	0.00
R^2 overall	0.04	0.06	0.10	0.11	0.20	0.20	0.23	0.30	0.41	0.43	0.39	0.27	0.26	0.25	0.23	0.25	0.21	0.10	0.05	0.03	0.01	0.01	0.01
F test *	14.46	20.60	23.86	17.00	19.31	24.22	33.35	36.75	41.00	48.08	53.97	50.41	51.54	57.07	61.32	63.68	60.39	50.68	49.80	43.52	39.37	32.82	30.10
F test (u_i =0) **	167.40	195.39	182.86	117.27	108.25	111.76	115.64	116.63	120.75	132.28	135.07	111.87	116.12	120.64	124.10	128.54	130.66	127.89	127.47	131.63	139.55	147.92	146.32
N. of obs.	88	107	125	142	160	173	198	221	245	269	298	318	352	387	422	462	486	516	547	538	523	504	486
EKC maximum	0.36	0.15	0.00	0.85	126.56	86.45	181.57	302.21	637.53	812.88	873.22	1151.74	1406.66	1519.54	1631.11	1602.57	1959.55	2300.61	1891.92	1742.49	1787.94	1610.03	799.32

Appendix A

Table A.1: 197 countries divided into World Bank Macro-Areas

East Asia and Pacific	Europe and Central Asia	Latin America and the Caribbean	Middle East and North Africa	South Asia	Sub-Saharan Africa	North America
American Samoa	Albania	Antigua and Barbuda	Algeria	Afghanistan	Angola	Bermuda
Australia	Armenia	Argentina	Bahrain	Bangladesh	Benin	Canada
Brunei	Austria	Aruba	Djibouti	Bhutan	Botswana	United States
Cambodia	Azerbaijan	Bahamas, The	Egypt, Arab Rep.	India	Burkina Faso	
China	Belarus	Barbados	Iran, Islamic Rep.	Maldives	Burundi	
Fiji	Belgium	Belize	Iraq	Nepal	Cameroon	
French Polynesia	Bosnia and Herzegovina	Bolivia	Israel	Pakistan	Cape Verde	
Guam	Bulgaria	Brazil	Jordan	Sri Lanka	Chad	
Hong Kong, China	Croatia	Cayman Islands	Kuwait	Afghanistan	Comoros	
Indonesia	Cyprus	Chile	Lebanon	Bangladesh	Congo, Dem. Rep.	
Japan	Czech Republic	Colombia	Libya	Bhutan	Congo, Rep.	
Kiribati	Denmark	Costa Rica	Malta	India	Cote d'Ivoire	
Korea, Dem. Rep.	Estonia	Cuba	Morocco	Maldives	Equatorial Guinea	
Korea, Rep.	Faeroe Islands	Dominica	Oman	Nepal	Eritrea	
Lao PDR	Finland	Dominican Republic	Qatar	Pakistan	Ethiopia	
Macao, China	France	Ecuador	Saudi Arabia	Sri Lanka	Gabon	
Malaysia	Georgia	El Salvador	Syrian Arab Republic		Gambia, The	
Marshall Islands	Germany	Grenada	Tunisia		Ghana	
Micronesia, Fed. Sts.	Greece	Guatemala	United Arab Emirates		Guinea	
Mongolia	Greenland	Guyana	Yemen, Rep.		Guinea-Bissau	
Myanmar	Hungary	Haiti			Kenya	
New Caledonia	Iceland	Honduras			Lesotho	
New Zealand	Ireland	Jamaica			Liberia	
Palau	Italy	Mexico			Madagascar	
Papua New Guinea	Kazakhstan	Netherlands Antilles			Malawi	
Philippines	Kyrgyz Republic	Nicaragua			Mali	
Samoa	Latvia	Panama			Mauritania	
Singapore	Lithuania	Paraguay			Mauritius	
Solomon Islands	Luxembourg	Peru			Namibia	
Thailand	Macedonia, FYR	Puerto Rico			Niger	

East Asia and Pacific	Europe and Central Asia	Latin America and the Caribbean	Middle East and North Africa	South Asia	Sub-Saharan Africa	North America
Tonga	Moldova	St. Kitts and Nevis			Nigeria	
Vanuatu	Netherlands	St. Lucia			Rwanda	
Vietnam	Poland	Suriname			Sao Tome and Principe	
	Portugal	Trinidad and Tobago			Senegal	
	Norway	St. Vincent and the Grenadines			Mozambique	
	Romania	Uruguay			Seychelles	
	Russian Federation	Venezuela, RB			Sierra Leone	
	Slovak Republic	Virgin Islands (U.S.)			Somalia	
	Slovenia				South Africa	
	Spain				Sudan	
	Sweden				Swaziland	
	Switzerland				Tanzania	
	Tajikistan				Togo	
	Turkey				Uganda	
	Turkmenistan				Zambia	
	Ukraine				Zimbabwe	
	United Kingdom					
	Uzbekistan					
	Yugoslavia, Fed. Rep.					

Table A.2: 197 countries divided into World Bank Income Levels

Low-income	Lower-middle-income	Upper-middle-income	High-income
Afghanistan	Albania	American Samoa	Aruba
Angola	Algeria	Antigua and Barbuda	Australia
Armenia	Belarus	Argentina	Austria
Azerbaijan	Belize	Barbados	Bahamas
Bangladesh	Bolivia	Botswana	Bahrain
Benin	Bosnia and Herzegovina	Brazil	Belgium
Bhutan	Bulgaria	Chile	Bermuda
Burkina Faso	Cape Verde	Costa Rica	Brunei
Burundi	China	Croatia	Canada
Cambodia	Colombia	Czech Republic	Cayman Islands
Cameroon	Cuba	Dominica	Cyprus
Chad	Djibouti	Estonia	Denmark
Comoros	Dominican Republic	Gabon	Faeroe Islands
Congo, Dem. Rep.	Ecuador	Grenada	Finland
Congo, Rep.	Egypt, Arab Rep.	Hungary	France
Cote d'Ivoire	El Salvador	Latria	French Polynesia
Equatorial Guinea	Fiji	Lebanon	Germany
Eritrea	Guatemala	Libya	Greece
Ethiopia	Guyana	Lithuania	Greenland
Gambia, The	Honduras	Malaysia	Guam
Georgia	Iran, Islamic Rep.	Malta	Hong Kong, China
Ghana	Iraq	Mauritius	Iceland
Guinea	Jamaica	Mexico	Ireland
Guinea-Bissau	Jordan	Oman	Israel
Haiti	Kazakhstan	Palau	Italy
India	Kiribati	Panama	Japan
Indonesia	Macedonia, FYR	Poland	Korea, Rep.
Kenya	Maldives	Puerto Rico	Kuwait
Korea, Dem. Rep.	Marshall Islands	Saudi Arabia	Luxembourg
Kyrgyz Republic	Micronesia, Fed. Sts.	Seychelles	Macao, China
Lao PDR	Morocco	Slovak Republic	Netherlands
Lesotho	Namibia	St. Kitts and Nevis	Netherlands Antilles
Liberia	Paraguay	St. Lucia	New Caledonia
Madagascar	Peru	Trinidad and Tobago	New Zealand
Malawi	Philippines	Uruguay	Norway
Mali	Romania	Venezuela, RB	Portugal
Mauritania	Russian Federation		Qatar
Moldova	Samoa		Singapore
Mongolia	South Africa		Slovenia
Mozambique	Sri Lanka		Spain
Myanmar	St. Vincent and the Grenadines		Sweden
Nepal	Suriname		Switzerland
Nicaragua	Swaziland		United Arab Emirates
Niger	Syrian Arab Republic		United Kingdom
Nigeria	Thailand		United States
Pakistan	Tonga		Virgin Islands (U.S.)
Papua New Guinea	Tunisia		
Rwanda	Turkey		
Sao Tome and Principe	Turkmenistan		
Senegal	Vanuatu		
Sierra Leone	Yugoslavia, Fed. Rep.		
Solomon Islands			

Low-income	Lower-middle-income	Upper-middle-income	High-income
Somalia			
Sudan			
Tajikistan			
Tanzania			
Togo			
Uganda			
Ukraine			
Uzbekistan			
Vietnam			
Yemen, Rep.			
Zambia			
Zimbabwe			

Table A.3: 48 countries used in constant estimations

Argentina	Japan
Australia	Kazakhstan
Austria	Korea, Rep.
Belgium	Latvia
Brazil	Malaysia
Bulgaria	Mexico
Canada	Moldova
Chile	Netherlands
China	New Zealand
Colombia	Nigeria
Croatia	Norway
Czech Republic	Pakistan
Denmark	Philippines
Estonia	Poland
Finland	Portugal
France	Romania
Germany	Russian Federation
Greece	Slovak Republic
Hungary	Slovenia
India	Sweden
Indonesia	Thailand
Ireland	Turkey
Israel	United Kingdom
Italy	United States

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(lxv) This paper was presented at the EuroConference on “Auctions and Market Design: Theory, Evidence and Applications” organised by Fondazione Eni Enrico Mattei and sponsored by the EU, Milan, September 25-27, 2003

(lxvi) This paper has been presented at the 4th BioEcon Workshop on “Economic Analysis of Policies for Biodiversity Conservation” organised on behalf of the BIOECON Network by Fondazione Eni Enrico Mattei, Venice International University (VIU) and University College London (UCL) , Venice, August 28-29, 2003

(lxvii) This paper has been presented at the international conference on “Tourism and Sustainable Economic Development – Macro and Micro Economic Issues” jointly organised by CRENoS (Università di Cagliari e Sassari, Italy) and Fondazione Eni Enrico Mattei, and supported by the World Bank, Sardinia, September 19-20, 2003

(lxviii) This paper was presented at the ENGIME Workshop on “Governance and Policies in Multicultural Cities”, Rome, June 5-6, 2003

(lxix) This paper was presented at the Fourth EEP Plenary Workshop and EEP Conference “The Future of Climate Policy”, Cagliari, Italy, 27-28 March 2003

(lxx) This paper was presented at the 9th Coalition Theory Workshop on "Collective Decisions and Institutional Design" organised by the Universitat Autònoma de Barcelona and held in Barcelona, Spain, January 30-31, 2004

(lxxi) This paper was presented at the EuroConference on “Auctions and Market Design: Theory, Evidence and Applications”, organised by Fondazione Eni Enrico Mattei and Consip and sponsored by the EU, Rome, September 23-25, 2004

(lxxii) This paper was presented at the 10th Coalition Theory Network Workshop held in Paris, France on 28-29 January 2005 and organised by EUREQua.

(lxxiii) This paper was presented at the 2nd Workshop on "Inclusive Wealth and Accounting Prices" held in Trieste, Italy on 13-15 April 2005 and organised by the Ecological and Environmental Economics - EEE Programme, a joint three-year programme of ICTP - The Abdus Salam International Centre for Theoretical Physics, FEEM - Fondazione Eni Enrico Mattei, and The Beijer International Institute of Ecological Economics

(lxxiv) This paper was presented at the ENGIME Workshop on “Trust and social capital in multicultural cities” Athens, January 19-20, 2004

(lxxv) This paper was presented at the ENGIME Workshop on “Diversity as a source of growth” Rome November 18-19, 2004

(lxxvi) This paper was presented at the 3rd Workshop on Spatial-Dynamic Models of Economics and Ecosystems held in Trieste on 11-13 April 2005 and organised by the Ecological and Environmental Economics - EEE Programme, a joint three-year programme of ICTP - The Abdus Salam International Centre for Theoretical Physics, FEEM - Fondazione Eni Enrico Mattei, and The Beijer International Institute of Ecological Economics

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