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Economic growth and environmental pressure: a worldwide panel analysis

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Economic growth and environmental pressure: A worldwide panel analysis

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Abstract

This paper deepens the consumption-based line of inquiry on the Environmental Kuznets Curve (EKC) question by means of a large panel dataset of world countries covering the 1961–2003 period. As indicator of environmental pressure, we employ ecological footprint estimates. The ecological footprint is a consumption-based measure, since it attributes the environmental impact of a given good or service to the final consumer, independently of where the supplying area is located. We measure income by means of *per capita* GDP expressed both in absolute and in purchasing power parity (PPP) terms. None of the estimated models show evidence of a de-linking between economic growth and environmental pressure for high levels of income. Hence, as a whole, our analysis does not support the EKC hypothesis.

Keywords: Environmental Kuznets curve; Ecological footprint; Displacement of environmental costs; Biocapacity; Population growth.

JEL classification: Q00; Q01; Q20; Q50; Q56; O13; R14.

1 Introduction

After the early studies by Grossman and Krueger (1995) and Shafik and Bandyopadhyay (1992), the literature on the Environmental Kuznets Curve (EKC) has expanded in many directions (reviewed for example in Stern 2004). In this paper, we focus on the consumption-based line of inquiry, started with the analyses by Ekins (1997) and Rothman (1998) who bring attention to the fact that increasing GDP may not induce a shift to a cleaner production process but rather to a relocation of production outside of the country, with an unchanged consumption pattern maintained via international trade. For this reason, both Ekins and Rothman argue that research on the EKC should also consider indicators of environmental impact or pressure centered on consumption, such as the ecological footprint (EF), alongside the usual measures of emissions, concentrations or withdrawals of natural resources.

The fundamental difference between a consumption and a production-based approach does not consist in measuring different sources of environmental pressure but in a different assignment of their responsibility.[1] Considering for example CO_2, a production-based approach assigns to each country all the emissions taking place within its boundaries, whereas a consumption-based approach assigns to each country the total CO_2 required to produce all the goods and services demanded by its population, irrespectively of where the emissions took place (see, e.g. Aldy, 2005; Bastianoni et al., 2004).

A few empirical investigations of the EKC hypothesis in a consumption-based perspective already exist. Among the earliest, Rothman (1998) proposes a concise analysis relating EF to GDP *per capita*, based on EF data covering 52 countries, finding no turning point within the data range. Suri and Chapman (1998) develop instead a cross-country analysis, using data on commercial energy consumption to investigate how international movements of goods embodying pollution impact on the income-environment relationship. Introducing trade variables (such as import-manufacturing ratios) in the model causes the turning point of the estimated EKC to move far beyond any attainable level of income per capita. Aldy (2005), using electricity-related emissions in the United States, brings this line of inquiry further by estimating pre-trade (production-based) and post-trade (consumption-based) CO_2 EKCs. He finds that the consumption-based curves reach a turning point at significantly higher incomes than the production-based ones. Jorgenson (2003) performs a cross-country analysis based on a wider EF dataset, and uses Kentor (2000) measure of world-system position (a combination of relative military power, economic power, and global dependence) as independent variable in place of GDP alone. He finds a direct, increasing relationship between world-system position and per capita ecological footprints. York et al. (2004) analyze cross-national variation in the ecological footprint per unit of GDP in order to study the behaviour of the ecological footprint intensity (or "eco-efficiency") of an economy when GDP rises — a question related to, although not coinciding with, the EKC hypothesis. EF intensity appears to be lower in affluent nations, but with an estimated variation not sufficient to compensate for the growth in the scale of the economy. Finally, Bagliani et al. (2008) do not find evidence of EKC behavior in a study based on a cross-sectional analysis of 141 countries relating GDP and ecological footprint. They also show that a country's biocapacity — i.e. an estimate of its

[1] The term 'production' in these studies is used with reference to the social metabolic processes by means of which all goods and services are generated, whether by firms or private individuals.

supply of natural capital — contributes to explaining its behaviour towards the environment: countries richer in natural resources tend to exhibit heavier ecological footprints.

The EF is a well known and widely used indicator of environmental pressure that estimates the amount of natural capital consumed by a given population (or economy) and expresses it in terms of a corresponding surface of biologically productive area (see Rees, 2003; Wackernagel et al., 1999, 2002). The ecological footprint of a country is the total biologically productive land required to produce all the goods and services consumed by its population (independently of where they were produced) and to absorb, using prevailing technology, the waste generated. For this reason, the EF is a consumption-based indicator: it counts the natural capital embodied in locally consumed goods and services, whether domestically produced or imported, and subtracts the natural capital embodied in exports. Since the implications of using EF data for EKC analyses are already extensively discussed in Bagliani et al. (2008), we will not go into further detail here.

Newly available, far more complete environmental datasets enable us to further develop the consumption-based line of inquiry by proposing, in this paper, an analysis of the relationship between ecological footprint and *per capita* income using a 1961-2003 panel covering almost one hundred countries. As far as we know, within the EKC literature this is the first panel study relying on a consumption-based environmental indicator, with the further advantage of an extremely wide and complete data coverage. We perform separate analyses on the whole dataset and on two subsets including OECD and non-OECD countries respectively, using fixed and random effect panel regressions. Population and biocapacity are used as control variables. As income measure, we use GDP expressed in both nominal and purchasing power parity (PPP) terms. None of the estimated models show evidence of a de-linking between economic growth and environmental pressure for high levels of income. As a whole our analysis does not support the EKC hypothesis.

The paper is organized as follows: Section 2 presents the dataset and discusses the econometric issues related to the analysis, section 3 presents the results of the model estimations, while section 4 discusses our findings.

2 Data and econometric method

The main source for our environmental data are the *National Footprint and Biocapacity Accounts, 2006 Edition* (Global Footprint Network, 2006), which includes ecological footprint and biocapacity estimations covering a period of 43 years (1961-2003) for 151 countries. Both EF and biocapacity are expressed in global hectares (gha). GDP and population data are instead excerpted from the *World Development Indicators* database (World Bank, 2006). GDP is expressed both in nominal terms (constant 2000 US Dollars) and in purchasing power parity (PPP), as constant 2000 International Dollars. For most countries, GDP observations cover the whole 1961-2003 period, while the PPP ones are limited to the 1975-2003 period.

In order to increase the robustness of the analysis (see Stern, 2004; Wagner, 2008), we selected in our database only countries having at least 29 observations[2], excluding as a consequence 53 out of the total 151 countries[3], when GDP is expressed in nominal terms,

[2]This figure represents the maximum number of observations included in the PPP database.

[3]The United Arab Emirates, the only strong outlier in the dataset, have been excluded from the analysis.

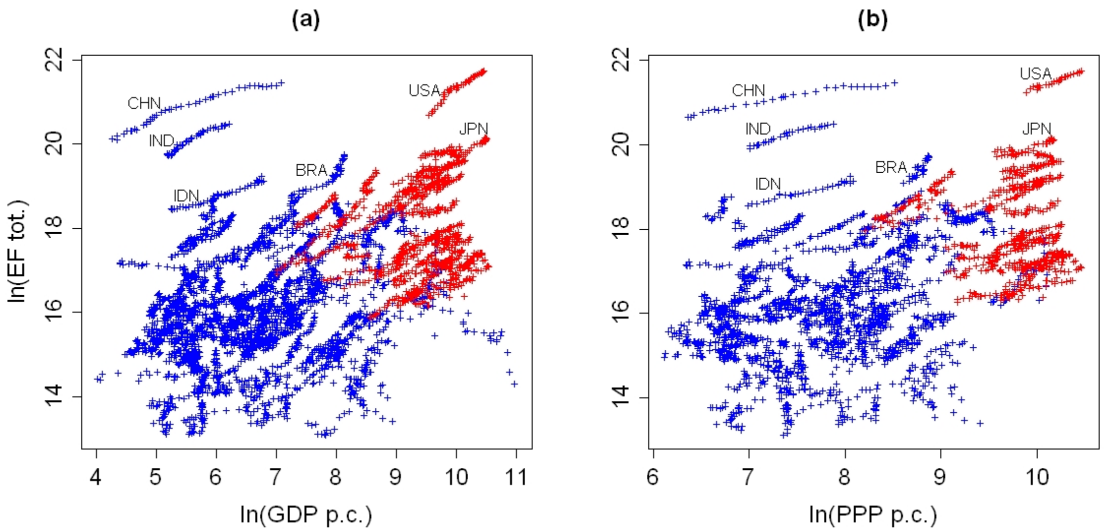

Figure 1: Observations of total EF in function of *per capita* GDP for all countries and all years included in the dataset. OECD countries are marked in red, non-OECD countries in blue. The labels show the position of some of the world major countries (ISO codes). Panel (a) shows data expressed in GDP in nominal terms, panel (b) shows data in PPP.

and 55 countries when GDP is expressed as PPP. Most of the excluded countries are less developed ones, which are not crucial for the EKC discussion. However, because of the discontinuity introduced by the 1991 dissolution of the USSR, the minimum requirement in terms of length of the available time series caused Russia and a number of other former-communist countries to be excluded as well, a fact that leaves an important area of the world underrepresented in our sample. Summarizing, our dataset encompasses 98 countries with 4120 observations when GDP is expressed in nominal terms, and 96 countries with 2784 observations when income is expressed in PPP.

Besides estimating the models for the whole sample, we also run separate analyses on two subsamples formed by the OECD and the non-OECD countries respectively. This distinction roughly reproduces the one between low-income and high-income countries and allows the analysis to account for different levels of technological, social and political development. While not totally satisfactory (a limited number of non-OECD countries has a *per capita* GDP higher than some OECD countries) splitting the sample on the ground of OECD membership is a procedure often used in the EKC literature (e.g. Galeotti et al., 2006; Schmalensee et al., 1998; Stern and Common, 2001), the main advantage being the independence of this criterion from the elements that represent the core of the EKC analysis. The OECD subset includes 25 countries with 1054 observations when the GDP is expressed in nominal terms, and 25 countries with 725 observations when it is expressed in PPP. The non-OECD subset encompasses 73 countries with 3066 observations when GDP is expressed in nominal terms, and 71 countries with 2059 observations when GDP is IN PPP. Figure 1 presents the complete plot of our observations.

The data in our dataset are available both in *per capita* and in total terms. Using one

Especially misleading is the unusual level of *per capita* GDP (above 50,000 USD) in the early '70s and its subsequent decline.

	GDP panel data		PPP panel data	
	$\chi^2(196)$	$\chi^2(196)$	$\chi^2(190)$	$\chi^2(190)$
Variable	(excluding t)	(including t)	(excluding t)	(including t)
$\ln(EF)$	200.75	599.75***	202.45	595.28***
$\ln(GDP)$	327.25***	150.99	175.24	170.81
$\ln(BIOC)$	319.95***	573.95***	356.78***	532.89***
$\ln(P)$	2025.91***	243.32**	1546.56***	163.65

Table 1: Fisher tests results for all the variables. Significance codes: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$.

or the other of the two specifications gives to the analysis a quite different meaning. The analysis in *per capita* terms draws a model of the relation between income growth and environmental pressure at the individual (actually, the average individual) level and it allows us to discuss theoretical questions on the environmental consequences of changes in individual income. However, the actual environmental impact in each country can be seen only looking at total data. Confirming the EKC hypothesis requires observing a decrease in the *total* pressure on natural systems once a given threshold in *per capita* income has been reached. A decrease in *per capita* environmental pressure, though significant in itself, could indeed be insufficient to reduce the overall environmental pressure in the face of a sufficiently strong rate of population growth.

In order to take account both of the marked demographic growth in almost all countries in the dataset during the 1961-2003 period and of the total environmental pressure, we regress each country total EF against *per capita* GDP, using as control variables each country's population and *per capita* biocapacity. The latter two factors both proved to be highly significant in influencing environmental pressure (measured by the EF) in (Bagliani et al., 2008)'s study of a cross-sectional sample of 141 countries. The same work showed that a cubic specification is often better suited than the standard quadratic one in fitting the relationship between GDP and EF. In this paper we hence estimate three models accounting for a linear, a quadratic and a cubic specification respectively and subsequently select the one that best fits the data.

We perform a preliminary analysis on the stationarity of our time series based on the Fisher test suggested by Maddala and Wu (1999) in case of unbalanced panels. In order to take into account the problems of stationarity evidenced by the test for all of our variables, we introduce in our models a time trend. As showed by a further Fischer test, this significantly reduces the non-stationarity of the variables (Tab. 1).

The specification of our model at the most general level is hence

$$\begin{aligned} \ln(EF)_{it} &= \alpha + \gamma t + \beta_1 \ln(GDP)_{it} + \beta_2[\ln(GDP)]^2_{it} + \beta_3[\ln(GDP)]^3_{it} \\ &\quad + \beta_4 \ln(BIOC)_{it} + \beta_5 \ln(P)_{it} + u_i + \varepsilon_{it} \end{aligned} \qquad (1)$$

where EF represents the total Ecological Footprint for country i at time t, GDP its *per capita* GDP, expressed either in nominal or in PPP terms, P is the country's population, $BIOC$ its *per capita* biocapacity, and $\varepsilon_{it} = \rho\varepsilon_{i,t-1} + z_{it}$, with $|\rho| < 1$ and z_{it} independent and identically distributed.

We estimate the above model using the regression model for panel data described in Baltagi (2001) and widely used in EKC-related literature (e.g. Aldy, 2005; Binder and Pages, 2005; de Bruyn, 2000; Stern and Common, 2001). The relationship between envi-

	Wald test for cross sectional Heteroskedasticity		Woolridge test for autocorrelation	
	GDP Model	PPP Model	GDP Model	PPP Model
All countries	70720.22***	35934.58***	572.21***	146.12***
OECD countries	2166.37***	1799.16***	1153.56***	179.65***
Non-OECD countries	21193.69***	33363.40***	492.27***	87.84***

Table 2: Wald and Woolridge test results. Significance codes: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$.

ronmental pressure and the regressors of the two general models is first analysed with a fixed effect (FE) approach, based on the Least Square Dummy Variable (LSDV) method. The same specifications of the models are also analyzed with a random effect (RE) estimation. The random effect approach is oriented to combine time and cross-sectional variability. A Breusch and Pagan (1980) test for random effects (BP) rejects for all models the null hypothesis that the u_i has a variance equal to zero, indicating the RE option as the most appropriate. We also apply a Hausman (1978) test in order to compare consistency and efficiency of the random effect versus fixed effect specification. The Hausmann test does not always confirm the result of the BP one.[4] Nevertheless, the responses of the Hausman test rely on the assumptions of the FE models (needed for the estimator to be consistent and efficient), which are violated by our panels: the countries do not appear to be independent, as required by the assumption underlying the fixed effect model. For all the LSDV specifications that best fit the ‘all countries’, ‘OECD’ and ‘non-OECD’ subgroups, we find cross-sectional heteroskedasticity and serial correlation of residuals. A modified Wald test suggests that our data exhibit a group correlation in the structure of error. Serial autocorrelation is also checked by the Woolridge test implemented by (Drukker, 2003), that confirms the presence of first order autocorrelated residuals (Tab. 2).

In order to deal with the above problems, a second group of models are calibrated with a feasible Generalised Least Squares estimator (FGLS), modified to account for cross-sectional heteroskedasticity and serial correlation through an AR1 structure of the idiosyncratic error with a country-specific ρ. Summarising, the available tests cannot univocally establish the superiority of fixed versus random effect models in analysing our dataset. We therefore Finally, the first set of fixed LDSV and FGLS corrected for autocorrelation are preliminarily estimated to examine also the time series properties of our panels, showing a systematic negative time trend factor in the behavior of residuals. We hence add a time trend factor to the list of explanatory variables of (1) to enhance the stationarity of residuals. In what follows, we present the results for LSDV and FGLS models estimated, including the time trend, as described in (1).[5]

[4]See Tab. 4, 5 and 6, and Section 3 for a detailed discussion of the results.

[5]Estimates of the reported FE specifications have been obtained with Nlogit 3.0, then controlled with Stata 8.0. FGLS models have been implemented with Stata 8.0 in order to check for differences in the estimations due to the software implementation of the models. We find no differences in the estimated parameters for at least the first three decimals. All the presented plots have been produced using R 2.7.0 (R Development Core Team, 2008).

Dataset	Variable	Coefficient	t	t^*	$P > t$
All	$\ln(EF)$	-0.4509	-29.4490	-14.2276	0.0000
countries	$\ln(GDP)$	-0.0337	-8.8980	-3.6644	0.0001
	$\ln(GDP)^2$	-0.0301	-8.1160	-2.9707	0.0015
	$\ln(GDP)^3$	-0.0260	-7.1720	-2.1133	0.0173
	$\ln(BIOC)$	-0.0630	-9.7400	-4.8443	0.0000
	$\ln(P)$	-0.0154	-23.3150	-24.5405	0.0000
	Residuals	-0.2308	-20.4330	-11.7551	0.0000
Non-OECD	$\ln(EF)$	-0.4655	-26.0170	-12.8605	0.0000
countries	$\ln(GDP)$	-0.0344	-7.3570	-2.6524	0.0040
	$\ln(GDP)^2$	-0.0309	-6.5790	-1.7687	0.0385
	$\ln(GDP)^3$	–	–	–	–
	$\ln(BIOC)$	-0.0787	-8.5130	-2.9516	0.0016
	$\ln(P)$	-0.0119	-7.4560	-5.8313	0.0000
	Residuals	-0.2810	-19.9880	-12.1178	0.0000
OECD	$\ln(EF)$	-0.4495	-14.7730	-7.0066	0.0000
countries	$\ln(GDP)$	-0.0362	-3.5170	0.6366	0.7378
	$\ln(GDP)^2$	–	–	–	–
	$\ln(GDP)^3$	–	–	–	–
	$\ln(BIOC)$	-0.2080	-9.6220	-6.1977	0.0000
	$\ln(P)$	-0.0187	-10.3400	-10.3479	0.0000
	Residuals	-0.1699	-8.0430	-3.7263	0.0001
	fd $\ln(GDP)^2$	-0.6759	-18.9130	-13.7196	0.0000

Table 3: Levin-Lin Stationarity test for the PPP dataset.

3 Data analysis

3.1 Stationarity analysis

Panel regression analysis requires, from an econometric perspective, to control for some time series properties of data. The presence of stochastic or deterministic non-stationarity in both dependent and explanatory variables may cause misleading responses about the presence f an EKC, if not controlled or adjusted in the implementation of models. Different tests that check for the presence of panel unit roots are available for balanced and unbalanced panels. For balanced panels, as is the case of the PPP dataset, we use the test proposed by Levin et al. (2002). It assumes the null hypothesis of non-stationarity of all series in the panel, against the alternative hypothesis that all series are stationary. It is the most restrictive test: other options are the Im-Pesaran-Shin test (Im et al., 2003) and the procedure proposed by Maddala and Wu (1999), that requires as alternative hypothesis that a fraction of the series (or even just one series) is stationary.

The application of the Levin-Lin test to the PPP panel shows overall support for the stationarity of the series for the $\ln(EF)$ and for both the regressors and the error term of random effect panels (Tab. 3). Only in the OECD subsample the PPP variable does not reject the presence of unit roots, even though the first differences of the variable (denoted as fd $\ln(GDP)^2$ in Table 3) are stationary. Limitedly to the OECD subsample (a conventional grouping rule) PPP series are more likely to assume the structure of a $I(1)$ process. However the relationships estimated for the all-country sample, which is the main focus of the paper, as well as for the non-OECD subsample, turn out to be fully stationary.

Unfortunately, the Levin-Lin procedure is not applicable for the panel encompassing GDP data expressed in nominal terms: the panel is unbalanced, with series longer than in the PPP case: 31, 32, 42 or 43 years of data, including some missing observations. We hence perform the unit root tests at a country level. An augmented Dickey-Fuller (ADF) test is employed for all the variables and for the residuals of the FE and RE models. We apply the same test on the differentiated variables to check for the presence of integrated first differences. More specifically, we account for cases that present stationarity of the first differences of $\ln(EF)$, of the three $\ln(GDP)$ variables and of the residuals. The full cointegration holds in the regressions on the GDP panel for 22 out of 98 countries in the FE model and for 23 countries in the RE one.

The overall outcome of this stationarity analysis shows that we do not expect to find spurious regressions for the PPP models. On the other hand, for the unbalanced GDP panel we find a certain level of cointegration, so we report both GDP and PPP outputs so as to enable an analysis of differences in the EKC behavior that may arise due to some not controlled non-stationarity.

3.2 All countries

The models estimated for all the countries in our dataset using GDP expressed in nominal terms prove to be highly significant. A Fisher test is used in order to choose the most appropriate specification. More specifically, we compare the cubic form described in (1) with the reduced quadratic and linear specifications using as null hypothesis a linear constraint on the values of β_2 and β_3. The test results in a preference for the cubic specification for both the FE and the RE model (Table 4).[6]

The two specifications offer a very similar picture, with a minimum at the very beginning of the data range (corresponding to per capita incomes of 143 and 194 USD respectively) and a subsequent monotonic increase: the turning point is reached at 13,842,407 and at 10,748,192 USD respectively, i.e. massively beyond any present or foreseeable per capita income level (Fig. 2a,b). Another interesting result is that, consistently with Bagliani et al. (2008) findings, both population and biocapacity coefficients are positive and highly significant, reflecting a strong direct relationship with the EF. Notice that population growth represents the main factor explaining the EF rise in the period under analysis, showing an effect that is even stronger than the GDP one.

The estimates obtained using the GDP expressed in PPP lead, similarly, to highly significant models. The Fisher test results in a preference for the quadratic, U-shaped specification in the FE model (Table 4). The curve shows a minimum at 602 International Dollars and is subsequently monotonically increasing (Fig. 2c). In the RE model, the best fitting curve is a cubic, again showing a minimum at low levels of income (926 International Dollars) and then increasing throughout the rest of the data range (a theoretical maximum is reached at 865,299 International Dollars, well above the upper limit of the data) (Fig. 2d). The relationship between both population and biocapacity and EF is again positive and highly significant.

[6] In order to limit the number of tables in the paper, Table 4, 5 and 6 report only the models that turned out to be the most appropriate on the ground of the Fisher test. Estimations for the other models are available from the authors upon request.

	GDP		PPP	
	Fixed Effects	Random Effects	Fixed Effects	Random Effects
$\ln(GDP)$	-1.2439***	-1.7466***	-1.7588***	-6.7969***
	(0.3868)	(0.2433)	(0.0783)	(0.8090)
$\ln(GDP)^2$	0.1631***	0.2197***	0.1374***	0.7461***
	(0.0544)	(0.0332)	(0.0047)	(0.0978)
$\ln(GDP)^3$	-0.0051***	-0.0068***	–	-0.0243***
	(0.0025)	(0.0015)	–	(0.0039)
$\ln(BIOC)$	0.1063***	0.0672***	0.0676***	0.0861***
	(0.0249)	(0.0066)	(0.0058)	(0.0069)
$\ln(P)$	1.0325***	0.9953***	0.9986***	1.0014***
	(0.0610)	(0.0039)	(0.0041)	(0.0047)
t	-0.0019	-0.0028***	-0.0048***	0.0005***
	(0.0014)	(0.0004)	(0.0007)	(0.0005)
Constant	8.7835***	9.5020***	8.7278***	28.4415***
	(1.0433)	(0.8880)	(1.542089)	(2.2449)
ρ	0.7147	0.8717	0.4955	0.8376
F	933.15***	–	397.37***	–
Wald χ^2	–	99001.51***	–	119728.21***
Hausman test	–	9.07	–	59.26***
BP test	–	37378.91***	–	19699.83***

Table 4: Regression results for all countries. Standard errors are in parentheses. Significance codes: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$.

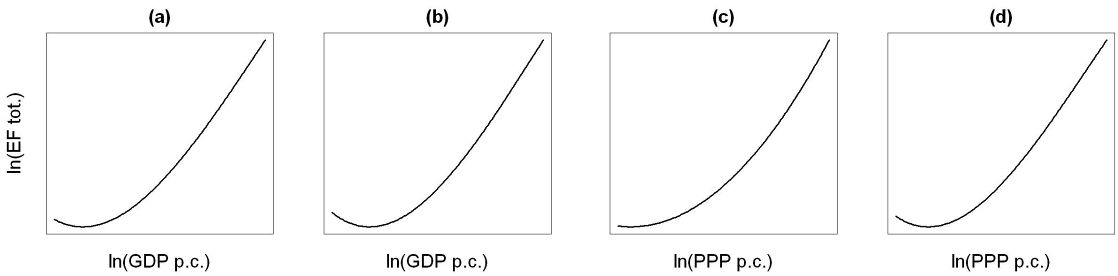

Figure 2: Partial regression plots for all countries. Panels (a) and (b) show the FE and RE models respectively with GDP data expressed in nominal terms. Panels (c) and (d) show the FE and RE models with GDP data expressed as PPP. The plotting interval on the x axis corresponds to the data range, the y axis one to its image.

3.3 Non-OECD country sub-dataset analysis

The estimates from the non-OECD subsample, using GDP expressed in nominal terms, are also highly significant. The Fisher test allows us to select the cubic specification for the FE model and the quadratic for the RE model (Table 5).

Both models show that, overall, EF increases directly with per capita GDP. More specifically, the FE model shows a minimum at the very beginning of the data range (138 USD) and a maximum at 197,358 USD, outside the upper limit of the data (Fig. 3a). The RE model has a minimum at 165 USD and is subsequently monotonically increasing (Fig. 3b). The Biocapacity and population coefficients are both positive and highly significant.

Estimating the model where the GDP is expressed in PPP lesds instead to the selection of quadratic specifications for both the FE and RE models (Table 5). The resulting

	GDP		PPP	
	Fixed Effects	Random Effects	Fixed Effects	Random Effects
$\ln(GDP)$	-1.5780***	-0.8121***	-1.0153***	-2.2599***
	(0.5097)	(0.0549)	(0.2532)	(0.1167)
$\ln(GDP)^2$	0.2249***	0.0795***	0.0840***	0.1680***
	(0.0741)	(0.0039)	(0.0162)	(0.0073)
$\ln(GDP)^3$	-0.0088**	–	–	–
	(0.0035)	–	–	–
$\ln(BIOC)$	0.0851***	0.0509***	0.0884**	0.0703***
	(0.0292)	(0.0075)	(0.0352)	(0.0083)
$\ln(P)$	1.0723***	0.9927***	1.2485***	0.9862***
	(0.0858)	(0.0044)	(0.0890)	(0.0052)
t	-0.0036*	-0.0037***	-0.0076***	-0.0031***
	(0.0022)	(0.0004)	(0.0022)	(0.0006)
Constant	4.8845***	9.3953***	13.93523***	13.7332***
	(1.4307)	(0.8918)	(2.112495)	(1.3341)
ρ	0.7147	0.8540	0.4955	0.8247
F	614.99***	–	1269.74***	–
Wald χ^2	–	61633.83***	–	119728.21***
Hausman test	–	21.57***	–	25.24***
BP test	–	22417.26***	–	14417.65***

Table 5: Regression results for non-OECD countries. Standard errors are in parentheses. Significance codes: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$.

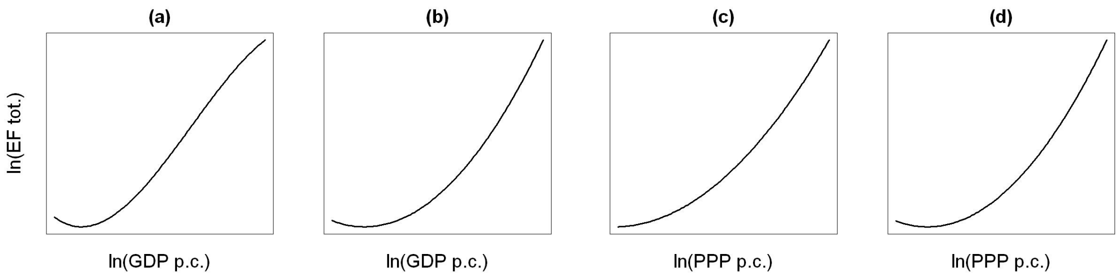

Figure 3: Partial regression plots for non-OECD countries. The (a) and (b) panels show the FE and RE models respectively with GDP data expressed in absolute terms, the (c) and (d) panels show the FE and RE models with GDP data expressed as PPP. The x axis plotting interval corresponds to the data range, the y axis one to its image.

parabolas show a minimum at the beginning of the data range (421 and 834 International Dollars respectively) and are subsequently monotonically increasing (Fig. 3c,d). As above, biocapacity and population coefficients are positive and highly significant.

3.4 OECD countries

The Fisher test on the coefficients of the model estimated on the OECD country subsample, with the GDP expressed in nominal terms, selects a linear specification for both the FE and RE models (Table 6): environmental pressure increases linearly with GDP (Fig. 4a,b). Both the biocapacity and population coefficients remain positive and highly significant.

A very similar picture emerges from the estimates on the OECD country dataset using

	GDP		PPP	
	Fixed Effects	Random Effects	Fixed Effects	Random Effects
$\ln(GDP)$	0.6206***	0.4439***	0.5224***	0.6491***
	(0.0432)	(0.0211)	(0.0491)	(0.0177)
$\ln(BIOC)$	0.2222***	0.1918***	0.2638***	0.1628***
	(0.0452)	(0.0131)	(0.0590)	(0.0089)
$\ln(P)$	1.1896***	1.0379***	1.1672***	1.0592***
	(0.1074)	(0.0121)	(0.1241)	(0.0122)
t	-0.0043***	0.0023***	-0.0013	-0.0056***
	(0.0013)	(0.0008)	(0.0014)	(0.0009)
Constant	-4.9026***	-8.3078***	-13.15509***	5.1676***
	(1.6040)	(1.5525)	(3.7521)	(1.5983)
ρ	0.7147	0.8977	0.4948	0.8353
F	3184.94***	–	2148.94***	–
Wald χ^2	–	9808.63***	–	9210.27***
Hausman test	–	18.30***	–	7.64*
BP test	–	10415.63***	–	3721.76***

Table 6: Regression results for OECD countries. Standard errors are in parentheses. Significance codes: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$.

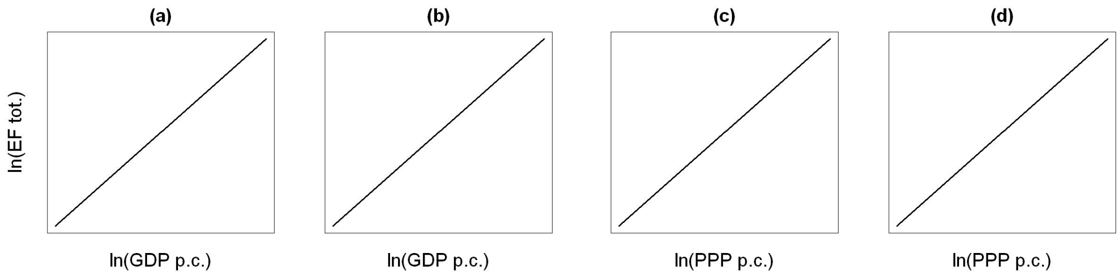

Figure 4: Partial regression plots for OECD countries. Panels (a) and (b) show the FE and RE models respectively with GDP data expressed in absolute terms. Panels (c) and (d) show the FE and RE models with GDP data expressed in PPP. The plotting interval on the x axis corresponds to the data range, the y axis one to its image.

the GDP expressed in PPP terms: the best fitting model is a monotonically increasing linear trend for both the FE and RE models (Table 6 and Fig. 4c,d). As in all the above models, the coefficients of both population and biocapacity are positive and significant.

4 Discussion and conclusions

A consumption-based approach to the EKC question had already casted doubts on the robustness of the hypotheses of de-linking between economic growth and environmental pressure for high levels of income. Our analysis, based on a large database covering more than 40 years of income and environmental pressure data for a large number of countries, strengthens this line of inquiry. The results question the EKC hypothesis, at least as long as environmental pressure is measured by a comprehensive consumption-based indicator such as the EF. None of the estimated models (considering the whole sample, as well as OECD and non-OECD countries taken separately; using GDP expressed in nominal as well as in PPP terms) supports the EKC hypothesis, thus suggesting a significant robustness of our conclusions. The non-conformity to the hypothesis of de-linking resulting from our study thus reinforces the outcome of previous consumption-based studies (e.g. Bagliani et al., 2008; Jorgenson, 2003; Rothman, 1998; York et al., 2004).

An interesting question is why our results depart so clearly from both early (e.g. Grossman and Krueger, 1995; Shafik and Bandyopadhyay, 1992; Shafik, 1994) and more recent (e.g. Galeotti et al., 2006; List and Gallet, 1999; List and Kunce, 2000; Paudel et al., 2005) studies that found instead EKC-compatible trends. Besides the criticisms that have been raised to the econometrics of some previous works supporting the EKC hypothesis (e.g. Bradford et al., 2005; Perman and Stern, 2003; Spangenberg, 2002; Wagner, 2008), two empirically relevant issues may help explaining the different outcomes: i) the fact that, most of the times, the observed EKC curves pertain to specific pollutants with relatively cheap end-of-the-pipe technological solutions, while the EF is a far more comprehensive indicator of environmental pressure; ii) the adoption of a consumption approach that takes into account the displacement of environmental costs. Let us consider these two issues in turn.

i) Starting from the work of Shafik and Bandyopadhyay (1992) and Grossman and Krueger (1995), most observed EKCs have been found with reference to specific local, or non-uniformly mixing, pollutants, such as carbon monoxide (CO), nitrous oxides (NO_x), suspended particulate or sulfur dioxide (SO_2). Cutting significantly the emission of these pollutants is often both technologically feasible using end-of-the-pipe solutions, like filtering, and relatively unexpensive to achieve. Studies using more comprehensive indicators — e.g. the throughput of material end energy in the economy (de Bruyn and Opschoor, 1997) or energy use, a proxy of total environmental impact, (Cole et al., 1997; Suri and Chapman, 1998) — are instead less likely to find EKCs (but Canas et al., 2003). Since the EF represents one of the most comprehensive available indicators of human pressure on natural systems, it is not surprising that our study does not find evidence of EKCs.

ii) Supporters of the consumption-based line of inquiry to the EKC questions argue that, even when an EKC is empirically found, it may reflect more the increased ability of wealthy consumers to distance themselves from the environmental consequences associated with their consumption than a true reduction of their environmental pressure. For instance, Mayer et al. (2005) show that forest protection measures in Finland and other European countries, without a simultaneous decrease in domestic wood consumption, simply resulted in a dramatically increased logging pressure abroad, and especially on Russian forests. Since the ecological footprint counts the natural capital embodied in locally consumed goods and services, both domestically produced and imported, it entails the attribution of environmental costs to the subjects that actually bear their ultimate responsibility (for a discussion, see Bastianoni et al., 2004). Consistently with previous studies adopting the same approach, the lack of support for the EKC hypothesis in our results suggest that the apparent de-linking between economic growth and environmental consequences, were it emerges, reflects more the capacity of wealthy consumers to displace elsewhere the costs of their own behavior than a real improvement of the global quality of the environment.

Worth mentioning are also the relevant impact found for biocapacity and population. Biocapacity represents a factor having a highly significant and positive effect in all our models. It implies that, all other things being equal, countries with higher *per capita* biocapacity tend to produce higher environmental pressure. A similar result had already emerged in Bagliani et al. (2008), which used a more limited cross-sectional dataset. The persistence of this outcome in our panel analysis suggests that it is not an artifact of cross-sectional analysis: some actual mechanism appear to exists that translates a more limited local environment into relatively lower environmental pressure, perhaps through higher citizens concern and/or political willingness to invest in environmental regulation. While this appears to be somewhat in line with some of the basic assumptions underlying the EKC hypothesis (but see Bravo and Marelli, 2007; Dunlap and York, 2008), we should remark that its effect is independent from income and does not represent a factor able to invert the relationship between income and environmental pressure.

A second factor showing a positive and highly significant relation with the EF is population. Actually, this is the most important driver of the growth in environmental pressure in all our models. This, again, is not surprising in itself since, in the period under consideration, almost all the countries included in the dataset had remarkable demographic growth rates. While the population effect is controlled in our models and does not hence alter the results on the existence of and EKC, population growth represents a crucial factor in itself for a wider discussion regarding the sustainability of the present development trends worldwide. Significant from this point of view is that, looking at the world-level EF time series, it is possible to observe that, while *per capita* EF reaches a peak at the end of the Seventies and subsequently stabilizes in the range of 2.23 ± 0.08 gha/pc, total EF steadily increased throughout the whole 1961–2003 period. This implies that, at least at the world level, population growth represents (along with economic growth) one of the key factors driving the environmental pressure increase.

To sum up, also taking into account population growth and different biocapacity endowments, the results of our analyses do not show evidence of a de-linking between economic growth and environmental impact for high levels of per capita GDP. The large number of countries included in the dataset and the relatively long period considered allow us to offer a stronger evidence than previous studies adopting a consumption-based approach to the EKC question. Studies focusing on production-based indicators and finding an eventual decrease of environmental impact for high levels of income in some countries may simply reflect a shift of pollution-intensive productions to other economies: a development path that can be enjoyed by a limited number of first-comer countries but cannot represent a general way to sustainability. The risk of falling into such fallacies is avoided by focusing on consumption-based indicators and we think that, as a whole, this line of inquiry is casting final empirical evidence against the EKC hypothesis.

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