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A Bayesian approach to the estimation of environmental Kuznets curves for CO_2 emissions

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Abstract

This paper investigates the EKC curves for CO_2 emissions in a panel of 109 countries during the period 1959-2001. The length of the series makes the application of a heterogeneous estimator suitable from an econometric point of view. The results, based on the hierarchical Bayes estimator, show that different EKC dynamics are associated with the different sub samples of countries considered. On average, more industrialized countries show an EKC evidence in quadratic specifications, which are nevertheless probably evolving into an N shape, emerging from cubic specifications. Less developed countries consistently show that CO_2 emissions still rise positively with income, though some signals of an EKC path arise.

Keywords: Environmental Kuznets Curve, CO_2 emissions, Bayesian approach, heterogeneous panels

JEL classification: C23, Q25

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1. Introduction

Since the pioneering works of Grossman and Krueger (1995) Shafik (1994) and Holtz-Eakin and Selden (1992) there has been considerable interest in the so-called Environmental Kuznets Curve (EKC). As widely known, the EKC hypothesis is shortly that for many pollutants, inverted U-shaped relationships between per capita income and pollution is documented. Applied investigations have mainly concerned major air emissions, though evidence for other externalities like local air and water emissions and, lastly, waste started to develop at the beginning of the century. We here focus on CO_2 emissions which have been recognized as a major source of environmental warning[1]. First, CO_2 emissions are directly linked to the production and consumption of energy and thus the shape of the relationship between CO_2 emissions and economic development has relevant implications for the definition of an appropriate joint economic and environmental policy. Secondly, empirical evidence in support of an EKC dynamics, or delinking between emission and income growth, has shown to be more limited and fragile in the case of CO_2 emissions with respect to local pollutants emissions and water pollutants (Yandle at al., 2002; Cole et al., 1997; Bruvoll and Medin, 2003). Decoupling between income growth and emissions of CO_2 is not (yet) apparent for many important economies in the world (Vollebergh and Kemfert, 2005), and when delinking is observed, it is of relative and not absolute kind as assumed by the usual EKC hypothesis (Fischer - Kowalski and Amann, 2001)[2].

The Kuznets hypothesis, from its origin outside the environmental arena, does not stems from a theoretical model, but it has followed a conceptual intuition and stylized facts, though recent contributions have started showing the extent to which the EKC hypothesis may be included in formalized economic models.

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1 "Pollutants like sulphur oxides or oxides of nitrogen, have a more local impact on the environment" (Azoumahou et al., 2006, p. 1348).

2 Only waste, which is a very different externality with respect to impacts and local dimension, shares with CO2 a lack of robust evidence in favor of absolute delinking (Mazzanti and Zoboli, 2005; Wang et al., 1998). Among main air emissions, CO_2 is the indicator for which evidence has been, and is, less shared across studies.

Theoretically based works have not been predominant in the EKC environment, though some contributions have emerged, with the aim of setting some foundations to the empirics of EKC. They generally aim at explaining the EKC dynamics by means of technological, externality type, preference based and policy factors. A seminal work is by Andreoni and Levison (2001), who suggest that EKC dynamics may be quite simply technologically micro founded, and not strictly related to growth and externalities issues. Kelly (2003) shows that the EKC shape depends on the dynamic interplay between marginal costs and benefits of abatement. Pasche (2002) theoretically address the role of technological change in goods and production as a pre-requisite for an EKC sustainable evolutionary growth of the economy. Smulders and Brteschger (2000) also provide an analytical foundation for the claim that the rise and fall of pollution may be linked to policy induced technological shifts. Some authors have recently suggested that for stock pollution externalities the pollution income relationship difficultly turn into an EKC shaped curve, with pollution stocks monotonically rising with income (Lieb, 2004).

At a more macroeconomic level, see Brock and Taylor (2004), for an integration of the EKC framework into the Solow model of economic growth; their amended model generates an EKC relationship between both the flow of pollution emission and income per capita, and the stock of environmental quality and income per capita, with resulting EKC either inverted U shape or strictly declining. Chimeli and Braden (2005) instead integrate EKC in a model of total factor productivity. Di Vita (2003) adds another possible founding argument, showing that the discount rate may play an important role in explaining for the income-pollution pattern observed. Low levels of income involve high values of discount rate, which are obstacles to the adoption of a pollution abatement policy. Only when the discount rate falls, as a consequence of growth, it is possible to implement measures for emissions reduction, leading to an inverse U-shaped income-pollution pattern. Dynamic preferences and growth issues in relations to EKC are also investigated by Chavas (2004).

Notwithstanding the increasing relevancy of theoretical studies on EKC, the quantitative side of the analysis is the one that has dominated the scene and it is still presenting room for research improvements at the margin. In fact, as far as econometric issues are concerned, despite some exemptions, macro-panel data studies have been generally based on the assumption of slope homogeneity across countries, using the classical fixed or random effects estimators or the more recent panel cointegration approach.

With the increasing of the time dimension of panel data sets, however, the choice of a more heterogeneous estimator could be suitable from an econometric point of view (Pesaran and Smith, 1995; Pesaran *et al.*, 1999; Hsiao *et al.*, 1999).

In this paper, we use a heterogeneous panel data estimators, derived from the Bayesian approach. In particular we apply the "hierarchical Bayes estimator" proposed by Hsiao et al. (1999) that has been shown to be preferable to other heterogeneous panel data estimators (Hsiao et al., 1999; Baltagi et al. 2004).

Our sample consists of 109 countries over the period 1959-2001. We do not control for possible determinants for CO_2 emissions, like energy prices or technological change. As pointed out by Azoumahou et al. (2006) several reasons can support this kind of econometric specification. The first two basic reasons concern data availability and comparability with the existing studies. The third one relies on a more econometric-founded consideration: although the specification without CO_2 emissions' determinants is not appropriate in order to measure the ceteris paribus impact of GDP on CO_2 emissions, this kind of econometric specification is a good tool for capturing the global effect of GDP on CO_2 including indirect effects linked with omitted variables which are correlated with GDP.

We first consider the issue of slope homogeneity across countries. For this purpose we focus on the Swamy (1970) random coefficients model and apply the χ^2 test statistics (Swamy, 1971) finding strong empirical evidence of heterogeneous slope coefficients across countries. Based on this result, we use the above mentioned "hierarchical Bayes estimator" in order to identify the average shape of the relationship between CO_2 emissions and per capita GDP, assuming slope heterogeneity across countries.

The paper is organized as follows. In section 2, we present a review of recent development in the analysis of the ECK for CO_2, focusing on the issue of heterogeneity of panel data estimators. Section 3 presents the econometric framework. Estimation results are in section 4 while section 5 concludes the study. Data sources and definitions are shown in the appendix.

1. Recent developments in study of the ECK for CO_2

We refer to Ekins (1997), Dinda (2004, 2005), Stern at al. (1996), Stern (2004, 1998), for critical and extensive surveys of the literature. This paper is strictly focused on (i) recent developments concerning the econometric panel methodology, with a specific emphasis on issues related to heterogeneity in panel data analyses, and (ii) evidence in the field of CO_2.

Though the number of studies on CO_2 is overwhelmingly higher, decoupling of income growth and emissions of CO_2 is not (yet) apparent from the facts for many important economies in the worlds (Vollebergh and Kemfert, 2005), and when delinking is observed, it is often of a relative and not of an absolute kind, as assumed by the usual EKC hypothesis.

Recent works have highlighted, on the basis of newly updated data and new techniques, that some evidence, even if differentiated by geographical areas and by estimation techniques, is emerging (Martinez-Zarzoso and Morancho, 2004; Vollebergh et al., 2005; Cole, 2003; Galeotti et al., 2006). Although evidence is patchy, i.e. heterogeneous across various attempts (which use different data with respect to time span and countries), it may be claimed that, some EKC evidence even for CO_2 is slowly emerging at least for OECD countries. A more optimistic picture is then mildly arising, counterbalancing some other less optimistic views (Harbaugh et al., 2002; Stern, 1998, 2004). Nevertheless, the overall evidence is far from being sound and results are to be cautiously interpreted.

Among the others, as examples of recent developments, Auci and Becchetti (2006) present evidence on CO_2 emissions in 1960-2001 for 197 countries from the WDI dataset. The paper specifies as dependant variable CO_2 emissions from aggregate fossil fuels domestic consumption per unit of GDP instead of CO_2 per capita. This allows the assessment of supply side effects, like scale and technology factors. EKC evidence is found for base and extended specifications, with turning points above the mean income level[3].

Recently, Cole (2005) applied the heterogeneous Swamy random coefficients estimator and concludes that the income-pollution relationship is found to vary widely across countries. This suggests that the assumption of constants coefficients across countries in the traditional fixed-effects specification is inappropriate. More fundamentally it suggests that there is no income-pollution relationship that is common to all countries and hence the very existence of a general EKC is questionable.

Most of the existing empirical literature applied pooled panel data estimators to samples of heterogeneous countries. Recent developments of the literature test the robustness of the EKC hypothesis either by using flexible parametric specifications, or by exploiting partially or fully non parametric models, or by looking at cointegration properties of CO_2 time series (Vollebergh et al., 2005; Galeotti, Lanza, Pauli, 2006; Galeotti, Manera, Lanza, 2006), producing mixed results, which do not help overcoming the intrinsic EKC empirical fragility. In a nut, the main criticism has been focused over recent years on the plausibility of standard "homogenous" panel when dealing with cross country analysis, where different income-CO_2 relationships may exist.

Dijkgraaf and Vollebergh (2005) and Vollebergh et al. (2005) allow for both heterogeneity across countries and flexible (non parametric) functional form and show that traditional panel models with country specific or country and time effects may present turning points within the observed income ranges; nevertheless the null hypothesis of slope homogeneity is strongly rejected by data, thus questioning the existence of an overall EKC and the homogeneity assumption.

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[3] Aldy (2005, 2006a,b) explores relationships among economic development, energy consumption and CO_2. He finds that the energy consumption income elasticity is positive but decreasing in income, though energy production takes an inverted U shape, peaking at 21500$ reflecting energy imports for richer states. The standard CO_2 measure, corresponding to energy production, peaks and follow EKC dynamics, while when adjusting mission for inter states electricity trade, an N shape emerges.

The first paper casts doubt on EC results stemming from homogenous panel estimation. They use a usual sample of 24 OECD countries over 1960-1997. On this basis they challenge the existence of an EKC dynamics for CO_2, at least for the overall picture of OECD countries, and suggest more in depth investigation at country specific level. Traditional panel models with country specific or country and time effects present turning points at around 14-15000$, nevertheless the null hypothesis of slope homogeneity is strongly rejected by data. A general model with slope heterogeneity show an higher turning point (20600$), all are in any case within the sample range. The most striking results is nevertheless that time series analysis, compared to heterogonous panel estimations, present a different picture. Only five out of 13 countries that showed an EKC dynamics confirm this outcome. They conclude that more work should be done on take series data, provided sufficient availability[4].

Vollebergh et al. (2005) consequentially explore various parametrical and non parametric specifications for a CO_2 dataset concerning OECD countries and find that EKC shapes are quite sensitive to the degree of heterogeneity included in panel estimations, further remarking the need of exploring not only heterogeneous panels specifications but also more flexible estimation tools. Parametric models generate EKC shapes with quite low turning points, while evidence is less robust for semi parametric estimations. In addition, they note that few observations on upper income and often small countries may produce strong effects on the EKC shapes. Thus, weighting is another issue that may undermine (homogenous) panel results. The non parametric setting demonstrates the necessity to incorporate heterogeneity, that leads to the exploration of single country specific time series, and to the suggestion of treating with care panel based EKC outcomes, moreover if they do not address in one way or another the heterogeneity issue.

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[4] They also point out than for some pollutants, like CO2, the lack of homogeneity is not a surprising outcome, given the trends in internationals specialisation, differences in local features and absence of strongly coordinated policies at least at international level.

They thus argue that differences in restrictions applied in panel estimation techniques are one of the main causes behind the divergence of findings in the EKC literature. Accounting for country heterogeneity is a crucial factor in EKC estimation; the inverted U shape curve is likely to exist for many (with higher income) but not all countries: homogeneity in EKC shapes is thus a too restrictive hypothesis. The existence of an EKC curve may depend, in cross country international framework like OECD based analysis, on the balance between high income countries showing an inverted U shape dynamics and high income countries which present a still positive elasticity of emissions with respect to income. Bringing together too different countries may present difficulties and lead to not easily interpretable and not so useful outcomes.

Galeotti, Manera e Lanza (2006) and Galeotti, Lanza and Pauli (2006) present a quite skeptical view on EKC and test the robustness of EKC hypothesis, analysing CO_2 series. The first paper is aimed at checking the robustness of EKC on a more fundamental ground than the test for omitted variables, different periods, and different parametric specifications. It addresses the very existence of the EKC dynamics on a statistical level, looking at the stationarity properties of the series; more specifically, they look at the cointegration properties of CO_2 time series by country. They conclude that, although unit root tests present some evidence in favor of the necessary stationarity, which provides economic and statistical meaningfulness to the EKC notion, further analysis is needed. The EKC still remains a fragile concept. We may affirm that, tough it is true that many factors may effect results, from the set of variables included to the specification used in parametric and non parametric frameworks, the bulk of accumulated evidence may provide scope for a sound meta-analysis of main findings, which seem to point out that some new evidence is emerging supporting EKC dynamics for OCED countries, while the CO_2 dynamics of non OECD is far away from presenting plausible turning points.

The latter show instead mixed evidence focusing on CO_2, and estimating different specifications varying set of emission data and the parametric structure of the model, but it concludes with a more optimistic perspective. Thus robustness is tested both on the basis of data typology and on the basis of alternative specification hypothesis. Results show that data sources seem to not affect EKC evidence. By exploiting a flexible parametric model such the Weibull functional form, an inverted U shape curve is found for OECD countries, regardless of data source used, while the EKC is basically increasingly for non OECD countries, but results are more dependent on data sources. Turning points are then found around 16000€ for OECD countries and between 16000 and 20000€ for non OECD countries, which, as expected, present less stable relationship between CO_2 and GDP, with respect to the source of data.

The commented papers have somewhat highlighted the role of semi parametric and full non parametric EKC estimations. Taskin and Zaim (2000) use non parametric production frontier techniques, establishing an EKC relationship by kernel estimation methodology. They exploit as dependant variable an environmental efficiency index ranging between 0 and 1, computed using cross section data for each year between 1975-1990, for 52 countries. Both kernel and parametric estimations show an N shape arising from the data: non parametric estimation gives robustness to the choice of a cubic specification. Turning points for the N shape curve are found at 5000 and 12000$ per capita.

Liu (2005) estimates a simultaneous model, in which GDP and CO_2 are jointly determined. In essence, he estimates both revenue and an emission function. He shows that including per capita energy consumption in the emission regression, thus taking the structure of the economy into account, implies a negative link between income and CO_2, which is contrary to main findings and reverse the usual evidence emerging when omitting this factor. If we assume that energy consumption is more correlated to the structure of the economy instead that to income, it is worth studying the relationship between emission and income holding the structure fixed. This may change results and the interaction of EKC dynamics.

Within the non-parametric arena, a recent paper is Azoumahou et al. (2006), who use CO_2 data over 1960-1996 for 100 countries, exploiting non-parametric and parametric specifications for comparison. The paper also discusses the recent evidence within the semi and non-parametric literature, arguing that functional issue is more of a concern than the heterogeneity issue. They compare different models, finding that EKC shapes arise when a parametric panel model is used (signs positive for linear and squared terms, and negative for cubic term), but instead a monotonous relationship emerges from both non-parametric settings and first difference regressions[5].

At the light of these recent developments, we argue that, with the increasing of the time dimension of panel data sets, the choice of a more heterogeneous estimator may be favorable from an econometric point of view (Pesaran and Smith, 1995; Pesaran *et al.*, 1999; Hsiao *et al.*, 1999).

We use the hierarchical Bayes estimator proposed by Hsiao et al. (1999) that has been shown to be preferable to other heterogeneous panel data estimators (Hsiao et al., 1999; Baltagi et al. 2004).

Our sample consists of 109 countries over the period 1959-2001 (see the Appendix for data source and definition). Given the length of the series, the application of a heterogeneous estimator could be suitable from an econometric point of view, and it adds value added to the literature of EKC in the field of CO_2 emissions.

The added value of the paper is twofold. We present evidence on CO_2 by exploiting a new method aimed at dealing with country heterogeneity. This is the methodological advancement. CO_2 is the only emission which currently present sufficient data availability for implementing this kind of quantitative methodology at international level. Secondly, in order to provide more economic and policy meaningful results, we test the EKC hypothesis on sub samples of countries (G7, OECD, EU_{15}, non-OECD, poorest countries), in order to compare those EKC trends with the total sample trend. We share the

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5 As far as Sulphur emissions are concerned, Halkos (2003) exploits a large panel dataset consisting of 31 years (1960-1990) and 73 OECD and non OECD countries, applying random coefficients and Arellano Bond GMM method. In the latter model the EKC hypothesis is not rejected. The study shows that such results are completely different from those obtained by using more usual fixed and random effects model. A semi parametric approach is exploited by Roy and van Kooten (2004), who examine the relationship between income and three non point source pollutants: CO, ozone and NOx (US 1990 data). Statistical tests reject quadratic parametric specification in favor of semi parametric model; data do not fit nevertheless with the inverted U shape hypothesis.

view that the EKC hypothesis is not applicable as a general concept, as it was present an overall cross country dynamic development of the emission-income relationship: many EKC shapes exist, specific to the country, the area and the time period we define.

2. Econometric approach

3.1 Estimation issues

The fact that the time dimension is allowed to increase to infinity in macro panel data has generated two sets of ideas. The first one applies time series procedures to panel, dealing with non-stationarity, spurious regressions and cointegration (Kao and Chiang, 2000; Phillips and Moon, 1999). The second one rejects the homogeneity of the parameters implicit in the use of a pooled estimator in favor of heterogeneous regressions.

Following this strand of literature and treating the parameters as fixed, one can estimate separate ARDL equations for each group and examine the mean of the estimated coefficients – the so-called Mean Group (MG) estimator (Pesaran and Smith, 1995). This estimator, however, does not take into account the fact that certain parameters may be the same across groups. For this reason, Pesaran, Shin and Smith (1999) propose an intermediate estimator, the so-called Pooled Mean Group (PMG) estimator which allows the intercepts, short-run coefficients and error variance to differ across groups while the long run coefficients are constrained to be the same.

An alternative way for building heterogeneous panel data estimators come from a Bayesian approach which treats the parameters as random, drawn from some distribution with a finite number of parameters. Recently, Hsiao and Tahmiscioglu (1997) and Hsiao et al. (1999) propose the Bayes and the hierarchical Bayes estimators which are build on the early work of Lindley and Smith (1972) and Swamy (1970): in fact the Swamy (1970) random coefficients model, motivated by classical generalized least squares arguments, can also be viewed as a Bayes estimator.

The choice between fixed and random coefficients formulation, however, despite the fact that it has been extensively discussed in literature, is difficult in practice (Hsiao *et al.*, 1995).

In the following, we apply the Hsiao et al. (1999) hierarchical Bayes approach to the estimation of an ECK for CO_2 emissions. Our choice is motivated by the fact that using both Monte Carlo experiments and an empirical example of a q investment model, Hsiao et al. (1999) find that this estimator is preferable to the other consistent estimators. Moreover, reconsidering the q-investment model and contrasting the performance of 9 homogeneous estimators and 11 heterogeneous and shrinkage Bayes estimators, Baltagi et al. (2004) find that the Hsiao et al. (1999) hierarchical Bayes estimator gives the best performance.

3.2 Econometric model and estimation methodology

We are interested in the estimation of the mean coefficients of a standard EKC function in presence of slope heterogeneity across cross-sectional units. Let us consider the following random coefficients specification:

(1) $$y_i = X_i\theta_i + u_i, \quad i = 1,\dots,N$$

Where $y_i = (y_{i1}, y_{i2}, \dots, y_{iT})'$ is the $(T \times 1)$ vector of observations for the dependent variable $(y_i = \ln(co_{2i}))$, namely the logarithm of CO_2 emissions per capita, and $X_i = (x_{i1}, \dots, x_{iT})'$ is a matrix of dimensions $(T \times k)$ of explanatory variables for the i'th cross-sectional unit. If we are interested in the estimation of a cubic formulation for the ECK, we obviously obtain a $(T \times 3)$ matrix of explanatory variables, given by: $X_i = \left(\ln y_i \vdots (\ln y_i)^2 \vdots (\ln y_i)^3\right)$ where y is GDP per capita. The disturbances are assumed to be heteroskedastic and uncorrelated across different cross-sectional units, i.e. $u_{it} \sim iid\left(0, \sigma_i^2\right)$ and $Cov\left(u_i, u_j\right) = 0$ if $i \neq j$.

We assume that $\theta_i = \bar{\theta} + \varepsilon_i$ where the ε_i are independently normally distributed with mean 0 and covariance Δ, i.e. $\theta_i \sim IN(0, \Delta)$ and $Cov\left(\theta_i, \theta_j\right) = 0$ if $i \neq j$. Each regression coefficient can thus be viewed as a random variable with a probability distribution. The random coefficients formulation reduces the number of parameters to be estimated, while still allowing the coefficients to differ across countries.

From a Bayesian point of view, Hsiao et al. (1999) focus on the inference of the mean coefficient vector, $\bar{\theta}$ conditional on *y* and the underlying model *M*, summarized in the posterior density $p\left(\bar{\theta}\,|\,y,M\right)$. The observations in *y* define a mapping from the prior $p\left(\bar{\theta}\right)$ into $p\left(\bar{\theta}\,|\,y,M\right)$. When there is reliable prior information on Δ and σ_i^2, the posterior distribution of $\bar{\theta}$ can be derived by expressing the likelihood function conditional on the initial values y_{i0} and combining it with the prior distribution of $\bar{\theta}$:

(2) $$p\left(\bar{\theta}\,|\,y,y_{i0}\right)\propto p\left(y\,|\,\bar{\theta}\right)p\left(\bar{\theta}\right).$$

Lindley and Smith (1972) discuss the derivation of the Bayes estimator of $\bar{\theta}$: they propose a three stage hierarchy method. Prior distributions for nuisance parameters, however, lead to integrals which cannot be expressed in closed form. Consequently, they propose a naïve approximation which consists in using the mode of the posterior distribution rather than the mean. However, a full Bayesian implementation of this model is now feasible as a result of recent advances in sampling-based approaches to calculating marginal densities. In particular, Hsiao et al. use the Gibbs sampling approach proposed by Gelfand and Smith (1990).

3. Results

We first consider the issue of slope homogeneity across countries. For this purpose we focus on the Swamy (1970) random coefficients model and apply the χ^2 test statistic suggested by Swamy (1971) for testing the null hypothesis of coefficients constancy across countries. This test is based on the differences between the OLS estimates equation by equation and a weighted average of the OLS estimates. Results strongly support the hypothesis of slope heterogeneity across cross-sectional units.

Assuming slope heterogeneity we apply the hierarchical Bayes estimator. Table 1 summarizes our estimates of $\overline{\grave{e}}$ obtained from the estimation of equation (1), highlighting the average shape of the income-carbon dioxide relationship and the eventual turning point, taking into account both a non limited income range and the observed income range. We consider both a quadratic and a cubic specification, as it is usual in the literature.

The hierarchical Bayes estimator requires prior information on the coefficients' distribution. For this purpose, we use the results obtained from the Swamy (1970) random coefficients regression estimator, which is a weighted average of the individual least squares estimates where the weights are inversely proportional to their variance-covariance matrices.

Results are the following. First, regarding quadratic specifications, the inverted U shape is validated for the full sample of countries, but not within the observed income domain, while for three of the five sub-samples (G7, EU15, OECD) the EKC hypothesis is robustly confirmed. Turning points are found for more developed areas in a range between 14.688$ and 18.607$ per capita (Table 1 shows observed income ranges).

Non-OECD and poorest countries, consistently with *a priori* expectations, show an opposite EKC picture. A monotonic increase of emissions with respect to GDP is robustly assessed by estimates without signs of reversal trends.

The full-sample analysis thus demonstrates to be a rough approach to EKC investigation. It hides regional and sub-sample evidence, showing its often-highlighted meaningfulness for economic and policy implications.

Secondly, further analyses are carried out by exploiting cubic specifications. They show their relevancy, since the picture slightly changes. The full sample presents an inverted N shape, but as before this analysis is less meaningful than specific geographical sub samples investigations.

For EU15 and OECD, a mixed picture emerges. An N shape arises considering the non limited income range. We however note that, within observed incomes the emerging shape is a typical Kuznets inverted U, with turning points at levels not different from above. It means that more industrialized countries have experienced an inversion in the emission/GDP relationship; at least on average in the regional aggregates, the path of economic growth seems to start re-boosting emissions more than proportionally. The N shape evidence is, plausibly, stronger for EU than OECD. Looking at turning point, while the higher peak of N is well within the income range, the second lower peak is quite higher than observed incomes (our levels are above 30.000$ per capita, 1990 constant prices). Emissions could then be characterized again in the near future by a positive elasticity with respect to GDP per capita. G7 actually presents a monotonous inverse of emissions, even without signs of EKC reversal, in any case.

This evidence is plausible. Vollebergh and Kemfert (2005) underlined that, on the one hand, technological change effects, complementarities between local and global emission reduction efforts and recent policies implemented by some wealthier areas may favor the re-shaping of the income- CO_2 relationship towards an EKC curve, or absolute delinking, and, on the other hand, the long term nature of CO_2 abatement benefits and the global dimension of agreements still act as counter balancing forces. EKC shapes with different ("high" and "low" as in an N-shaped curve) turning points arising over time may be compatible with the dynamics of industrialized countries. Scale effects are mitigate and somewhat reversed by supply side and demand side effects, as well as by emerging policies, nevertheless along a non linear path.

Finally, evidence for non OECD and poorest countries cases highlights signs of the three income terms that are, respectively: negative, positive and negative. This implies an "inverted N shape" dynamics, which would imply a potential EKC dynamics for less developed countries. In any case both non OECD countries and the 40 Poorest (consistently) present monotonic relationships within the income range, confirming quadratic specifications outcomes. The only turning point observed for non OCED countries is largely outside the income range.

Summing up, we observe that in both quadratic and cubic specifications, the full sample analysis, as also suggested by the literature, hides more interesting and critical dynamics, differentiated by areas and/or development level. Both quadratic and cubic specifications lead to an EKC dynamic for the more developed countries. Monotonously-rising emissions, with respect to GDP, are instead observed as expected for lower developed countries. The cubic specifications add other evidence. More industrialized countries may be experiencing a new dynamic where the elasticity of emission with respect to GDP turns back to a positive value, after a phase of decrease. The turning points at which both inversions occur are the one well below 20.000$ per capita, and the other beyond 30.000$. Stocking to observed income ranges, the EKC hypothesis is valid for more industrialized countries.

Developing countries instead experience, according to the cubic regressions, a monotonous increase of CO_2, with only some weak signals in favor of EKC shapes, but with a turning point well outside the income range[6].

Aggregate evidence, in terms of average slope coefficients- is still against the EKC dynamics; further research could be carried out on specific countries, at both industrialized and industrializing level. Our evidence in any case provides specific tests on sub-samples of countries, showing the added value of such estimates with respect to full samples ones.

4. Conclusion

The paper offers evidence in favor of an EKC-like dynamics of CO_2 emissions. This new evidence adds robustness to similar recent results, since it exploits a hierarchical Bayes estimator consistent with long time series in panel data. Evidence of an EKC relationship between emissions per capita and income per capita (international 1990 dollars) is here found. As expected, it is nevertheless limited to the OECD, G7, and EU15 areas. A monotonic

[6] The EKC trend of non OECD countries has recently been, and it will be more and more driven, by fast growing and high energy consuming countries like India and China. Meuniè (2004) exploits data for the 30 Chinese regions for 1990-1999, and finds for CO_2 some initial evidence in favor of the EKC. The peaks are quite sensitive to the specification used, ranging from 2900 to 8500 Yuan (1995) per capita.

relationship between income and emissions still characterizes less developed countries. Results for the cubic specification also warn about the possible emergence of an N shape dynamics of CO_2 emission paths for industrialized countries.

The existence of EKCs does not imply that sustainability is achieved as a necessary outcome of economic growth. In a policy perspective, evidence on EKC should not give the wrong deterministic suggestion that a rapid growth towards high levels of GDP per capita automatically drives to 'absolute' or 'relative' delinking between CO_2 emissions and income, and then growth would be the best 'policy strategy' to reduce environmental impacts. In fact, GDP growth also implies a direct 'scale effect' on emissions and, if it is not enough intensive of innovations leading to emission efficiency (per capita and/or per unit of GDP) the 'scale effect' of income growth on emission may prevail. The possible emergence of N-shaped EKCs as well as other complex configurations of the growth-emissions relationship, and the country/region specificity of EKCs as resulting from our analysis, should warn about the non-deterministic nature of the relationship between growth and the environment. Even in presence of sustained growth, policy should not take a passive attitude towards controlling emissions.

The main added value of exercises aiming at refining the identification and measure of EKC relationships by employing new techniques, as the one carried out in this paper, is to make this complexity and differentiation to emerge. We argue that the proposed method is a valuable too for cross country EKC analyses. Provided the problems posed by heterogeneity for examining and interpreting internationally focused datasets, research alternatives are time series or panel analysis at country level exploiting regional/provincial heterogeneity[7]

These exercises, however, cannot substitute for explicit analyses of the economic and technological factors possibly leading to EKC-like dynamics,

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[7] List and Gallet (1999) and Managi (2006) as examples for the US.

such as complex endogenous dynamics of economic systems, energy/emission innovations, and the effects of policies.

Appendix. Data sources and definitions

Data on emissions are from the database on global, regional, and national fossil fuel CO_2 emissions prepared by Marland, Boden and Andres (2005) for CDIAC, Carbon Dioxide Information Analysis Center, U.S. Department of Energy (available at cdiac.esd.ornl.gov). The database includes data on emissions dating back to 1751 for the global level and some countries, and for 1950-2002 for the majority of countries. The latter data are derived from energy statistics published by the United Nations in 2005 using the methods of Marland and Rotty (1984). In this paper, we used the subset of emission data matching with the available time series on GDP per capita on the basis of joint availability, series continuity, and country definitions. This resulted in a sample of 109 countries for the period 1959-2001.

Data on GDP per capita for all the 109 countries are from the database on the historical statistics of the world economy based on Maddison (2002) and managed by the OECD (www.theworldeconomy.org). Data on GDP per capita for all countries are in 1990 International 'Geary-Khamis' dollars, as used in the International Comparison Program (see unstats.un.org/unsd/methods.htm for details).

For country groups/aggregations, we adopted the present official composition of G7, EU15, and OECD. The non-OECD group includes all 109 countries excluding OECD countries. The group of 40 Poorest includes the 40 countries with the lowest per capita GDP in our sample.

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Table 1. Hierarchical Bayes Estimations (dependent variable: $\ln(CO_2)$)

	Quadratic specification						Cubic specification					
	Full sample	G7	EU15	OECD	NON-OECD	40Poorest countries	Full sample	G7	EU15	OECD	NON-OECD	40Poorest countries
Constant term	-9.98*** (0.15)	-50.9*** (0.08)	-50.9*** (0.06)	-42.4*** (0.08)	0.42*** (0.05)	0.30*** (0.06)	6.61*** (0.03)	-482*** (0.05)	-395*** (0.02)	-132*** (0.01)	11.11*** (0.05)	-6.39*** (0.07)
ln(y)	1.96*** (0.04)	10.91*** (0.09)	10.76*** (0.08)	8.91*** (0.08)	-0.29*** (0.03)	-0.16*** (0.03)	-2.74*** (0.03)	145*** (0.07)	118.9*** (0.02)	31.7*** (0.01)	-4.53*** (0.03)	3.09*** (0.06)
$(\ln(y))^2$	-0.08*** (0.004)	-0.56*** (0.02)	-0.56*** (0.01)	-0.45*** (0.01)	0.04*** (0.004)	0.02*** (0.005)	0.35*** (0.007)	-14.6*** (0.09)	-11.8*** (0.03)	-2.24*** (0.03)	0.59*** (0.01)	-0.50*** (0.015)
$(\ln(y))^3$							-0.01*** (0.002)	0.49*** (0.09)	0.39*** (0.03)	0.04* 0.024	-0.02*** (0.002)	0.03*** (0.005)
Shape1	Inverted U	Inverted U	Inverted U	Inverted U	U	U	Inverted N	monotonic	N	N	Inverted N	monotonic
Shape 2	monotonic	Inverted U	Inverted U	Inverted U	monotonic	monotonic	Inverted N	monotonic	Inverted U	Inverted U	monotonic	monotonic
Per capita GDP range	201-43806	3553-28129	2794-23201	1105-28129	201-43806	201-2991	201-43806	3553-28129	2794-23201	1105-28129	201-43806	201-2991
Turnings points	Out 1.045×10^5	14688	16105	18607	Out 62	Out 71	535; 32338		17693; Out 32533	13179; Out 1.23×10^{12}	Out; Out 186 1.86×10[illegible]	
χ^2 test of coefficients constancy	1.3e+05***	14023***	18173***	50713***	59213***	16989***	1.7e+04***	1965***	10862***	14143***	21422***	14632***

Notes.
Standard errors between brackets
*: significant at 10% level; **: significant at the 5% level; ***: significant at 1% level
Shape1 indicates the shape of the relationship considered in the domain interval $\infty < y < \infty$
Shape2 indicates the shape of the relationship considered in the domain interval defined in the range of the observed values
Per capita GDP range and turnings points are expressed in dollars 1990
Out indicates that the turning points are located outside the domain interval of per capita GDP

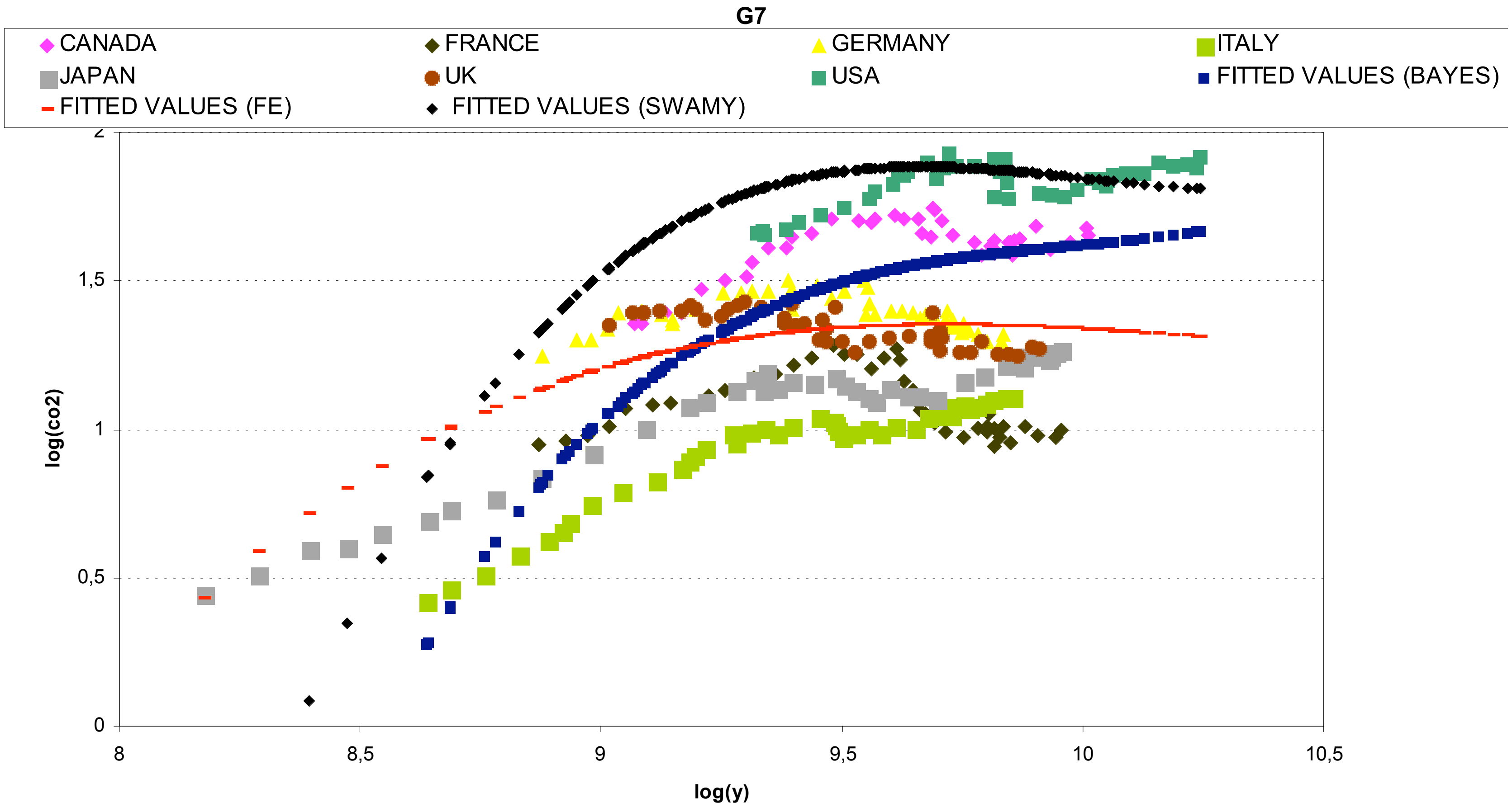

Figure 1. Real and fitted values – Cubic ECK specificatio