Università degli Studi di Ferrara
Dipartimento di Economia Istituzioni Territorio
Via Voltapaletto, 11 – 44100 Ferrara

Quaderno n. 6/2009

March 2009

Carbon Kuznets curves: long-run structural dynamics, Kyoto 'coalitions' and policy events

Massimiliano Mazzanti Antonio Musolesi

Carbon Kuznets curves: long-run structural dynamics, Kyoto 'coalitions' and policy events

Massimiliano Mazzanti & Antonio Musolesi[♠]

Abstract

We study the structural differences among climate change leading 'actors' - Northern EU members -, and lagging actors - southern EU countries and the 'Umbrella group' - with regard to carbon-income relationships. Homogeneous and heterogeneous panel models show that the groups of countries less in favour of stringent climate policy have yet to experience a Kuznets curve, though they show relative delinking. Northern EU instead robustly shows bell shapes. Exogenous policy events such as the 1992 climate change convention appear to be relevant in shaping the EKC of Northern EU. In addition, other events such as the second oil price shock appear to have also impacted in shaping the long run emission/GDP dynamics.

Keywords: Carbon Kuznets Curve, panel cointegration, heterogeneous panels, cross-section correlation, Kyoto framework, Bayesian models, policy events, long run dynamics

JEL classification: C23, Q53

[♠] Respectively University of Ferrara & CERIS CNR (National Research Council of Italy) Milan, Italy; and CESAER INRA UMR 1041, Dijon, France. Corresponding author Massimiliano Mazzanti, Department of Economics Institutions and Territory, via Voltapaletto 22, Ferrara, Italy, mzzmsm@unife.it

Introduction

Indicators of decoupling, that is improvements in environmental/resource indicators with respect to economic indicators, are increasingly being used to evaluate progress in the use of natural and environmental resources (OECD, 2002; EEA, 2003). Stylised facts have been proposed on the relationship between pollution and economic growth, which became know as the Environmental Kuznets Curve (EKC) hypothesis, that has gained an increasing research attention over time since the pioneering works of Grossman and Krueger (1995), Shafik (1994) and Holtz-Eakin and Selden (1992).

Applied EKC investigations mainly focus on emissions into the air, although evidence for other types of emissions and pollutants, such as waste, has been emerging. In this paper we focus on CO_2 emissions which have been recognised as a major source of environmental pollution (Schmalensee *et al.*, 1998), and offer the most robust data for applying advanced econometric techniques. The relevance on carbon is also depending on the fact that if one the one hand absolute delinking have been experienced and verified in the literature for local and regional air and water emissions, CO_2 (and waste generation) are environmental impacts that have not shown clear and robust EKC shapes, if not for specific countries and sectors in advanced economies[1]. Even in advanced economies nevertheless the evidence is far from assessing a neat absolute delinking overall (Cole et al., 2003, 1997; Mazzanti et al., 2008, Stern, 2004; Dinda, 2004). Decoupling between income growth and CO_2 emissions is not (yet) apparent for many important world economies, and where it is observed, it is relative rather than absolute as usually assumed by the EKC hypothesis.

This paper aims to contribute to the development of EKC research in two main directions. First, we use modern econometric panel approaches capable of providing new evidence on EKC long run dynamics. We employ homogeneous estimators and more recent estimators derived from panel cointegration analysis as well as heterogeneous estimators which allow individual slopes to be derived from sampling or Bayesian approaches. It is difficult *a* priori to decide between homogeneous and heterogeneous panel estimators. On the one hand, the increasing time dimension means that the slope homogeneity implicit in the use of a pooled estimator is questionable. On the other hand, most researchers agree about the use of homogeneous estimators since the efficiency gains from pooling often overcome their costs (Baltagi *et al.* 2000, 2002, 2004). Some researchers have suggested using "intermediate" estimators as Bayesian shrinkage estimators (Maddala *et al.* 1997) or the Pooled Mean Group (PMG) estimator (Pesaran *et al.,* 1999), allowing intercepts, short-run coefficients and error variances to differ freely across cross-sections, while long-run coefficients are held constant.

Secondly, we focus on a policy relevant scenario, in which pro-Kyoto countries and the Umbrella Group, respectively led by the EU and the US, are compared in their EKC delinking performances. The main issue we address looking at a long run dynamics including the 1992-2001 pre and post Kyoto

---

[1] Some emissions have shown robust TPs at quite low levels of income ($10,000-20,000), such as SOx, Nox and PM.

period, is why were some countries in favour of cutting CO_2 emissions and others opposed. A part of the underlying answer may be connected with the eventual historical decoupling of CO_2 and GDP, and 'policy-related' structural factors. More specifically, we may assume that the reason why some countries (EU, and within EU the northern countries including UK) supported Kyoto from the beginning and are supporting stricter targets (the 20-20-20 EU opposed plan on energy and environmental efficiency) is that they took early actions in terms of economy restructuring and environmental policies. As early movers, they wanted to exploit the benefits related both to the 'Porter' competitive advantages linked to new green technology markets[2] and to the intrinsic advantage of reasoning in terms of CO_2 reductions decided in 1997 with respect to 1990 levels. What happened between 1992 and before, and 1997 mattered. Early movers could take advantage of Kyoto targets more than others.

Moreover, a lower elasticity and/or EKC evidence for a group (Northern EU) could explain stronger support for Kyoto, deriving from better historical environmental performance and favourable structural conditions. Nevertheless, this is the 'average picture'; reasoning at the margins, the current achievement of EKC shapes could be associated with higher marginal abatement costs, than reduced incentives for further efforts, if one excludes the objective of intensifying green and economic competitive advantages spurred by innovation investments (Jaffe et al., 1995; Mazzanti e Zoboli, 2009). In terms of current policy negotiations, structural differences in EKC shapes could inform the allocation of burdens in the Kyoto 2 phase (beyond 2012) for maximising economic efficiency at global level.

Though policy implications may be linked to the analysis of EKC paths, we believe that the literature has so far provided weak evidence. We shed light on such policy implications by taking quite a different angle from usual EKC analyses. In fact, the policy oriented reasoning is key and derive both from (i) a comparative assessment of EKC shapes for three group of countries, instead of analysing larger samples (OECD): the Umbrella group, EU south and EU northern countries[3], (ii) a series of structural break test on the relevance, in affecting the CO_2 income time series, of exogenous political events, such as the 1992 Convention on climate change, the Kyoto protocol, searching also for other sources of structural break. We bring together policy analysis and the study of advanced econometric methodologies, including 'intervention analysis' aimed at highlighting how exogenous (policy) events affect a long run structural dynamics. As recognised, policy events may be needed to reshape the business as usual EKC, by smoothing the bell and/or decreasing the income TP level. Economic

[2] It is well recognised that part of the opposition to the anti Kyoto Us position made explicit at the convention in Johannesburg in 2002 came from environmental technologies sectors.

[3] The Umbrella group has supported a radical interpretation of the EKC: economic growth that drives technological improvements is what is needed to achieve a sustainable path. The EU supports the hypothesis that policy making should target the climate change 'business as usual' (BAU - no policy) by favouring the emergence of an EKC, and eventually the turning point (TP) level of the carbon Kuznets curve.

growth matters for achieving higher environmental efficiency, but is not sufficient for sustainability. We provide some evidence on such issue.

Although the political agenda is changing, mainly in the US[4], our aim is to provide food for thought for political negotiators in the context of the post Kyoto era, by examining the extent to which the structural differences of different 'groups' of countries might explain their different policy perspectives and economic capabilities to tackle the climate change issue. Our Empirical evidence provides useful information for: (i) the current scenario, in which the US is slowly coming to recognise the need to tackle climate change, but favours flexible policy instruments, and the EU is leading Kyoto implementation (Kruger and Pizer, 2004; see also the update developed in *Resources for the Future*); and (ii) the post Kyoto negotiation round, which should set the framework for the new climate change policy scenario. We argue that compared to studies based on OECD country or world wide datasets,[5] a focus on specific regions, and groups of homogenous countries, would provide a sounder basis for economic and policy reasoning. Economic and statistical aspects should be considered jointly in the environmental economic/policy arena.

The paper is structured as follows. Section 1 provides an updated picture of evolution in the theoretical aspects of EKC, and highlights the more interesting empirical analyses. Section 2 presents and discusses the set of homogenous, heterogeneous, shrinkage and spatial panel estimators and the dataset. Section 3 comments on the main results of the analysis and Section 4 concludes with a summary of results and some policy implications.

1. The EKC state of the art

1.2 Theoretical underpinnings: recent developments

The EKC literature has moved from basic conceptual intuitions and stylised/empirical facts, which traditionally fed EKC analysis, to the search for theoretical foundations for EKC empirics. Such models generally try to explain EKC dynamics by technological, externality type, preference based and policy factors. An extensive overview of the main theoretical issues can be found in Copeland and Taylor (2004).

Andreoni-Levinson (2001) provide a seminal work that suggests that EKC dynamics may be quite simply technologically micro founded, and might depend on increasing returns to scale, rather than being related strictly to growth and externality issues. Other works provide technology based explanations for the EKC path. Jaeger and van Kolpin (2008) show that the sufficient conditions for

[4] We may say that the 'green economy revolution' now emphasised (even) in the US is partly depending on political changing and on the current economic depression. A way out of the crisis is to spur investments in greener technologies towards a new (green) economy. We will see that the 'crisis argument' has other implications in our study.

[5] Most works included in our overview focus on world wide datasets (Azomahou et al., 2006), which are often based on OECD countries as a set (e.g. Cole, 2005; Galeotti et al., 2006; Martinez-Zarzoso and Bencochea-Morancho, 2004). However, within the OECD group there is great heterogeneity in terms of the stage of development of economies, and taking these countries as a group is not relevant in our eyes.

EKC are identified by a range of models and parameters in production functions settings, including homothetic, constant returns to scale (CRS), CES functions. Pasche (2002) addresses theoretically the role of technological change in goods and production as a pre-requisite for an EKC sustainable evolutionary economic growth. Smulders and Bretscgher (2000) provides an analytical foundation for the claim that the rise and fall in pollution may be linked to policy-induced technological shifts. Kelly (2003) focuses on environment related technology showing that the EKC shape depends on the dynamic interplay between marginal costs and the benefits of abatement.

Analyses based on dynamic models are attracting increasing attention from scholars interested in assessing EKC roots. At the macroeconomic level, Brock and Taylor (2004) claim for the integration of the EKC framework within the Solow model of economic growth. A similar dynamic theoretical analysis based on endogenous growth model is provided by Dinda (2005), who focuses on the dynamic allocation of capital between two sectors (production and abatement), in order to see whether EKC are coherent with socially optimal paths. While Chimeli and Braden (2005, 2008) integrate EKC in a total factor productivity (TFP) model, and looks at the role of capital scarcity theory, Khanna and Plassmann (2007) respond, maintaining that a general condition exists, not dependent on either differences in TFP or decreasing returns to abatement. The income-pollution link is instead driven by contemporaneous changes in the marginal rate of substitution between environmental quality and consumption on the demand side, and the marginal rate of transformation between those goods on the supply side. Anderson and Cavendish (2001) exploit simulation analysis by including policy analysis in their study.

Finally, since the seminal work by Arrow and Fisher (1974), the role of irreversibility and uncertainty of development has been crucial to explain sustainable economic growth. Prieur (2007) notes that economic growth may be accompanied by the accumulation of ecological debt, but, due to the irreversible nature of some pollution, the debt may be such that, once the economy engages in maintenance, the effort is not sufficient to avoid the irrevocable degradation of the environment. Ranjan and Shortle (2007) links stock effects and irreversibility issues, claiming that points of no return can occur if hysteresis effects are associated with pollution accumulation. It is possible to revert back, and to drive a path to more sustainable levels only if certain threshold combinations of capital and degradation accumulation are not crossed.

1.2 Towards new applied directions

Recent works have highlighted, on the basis of newly updated data and new techniques, that there is some evidence supporting EKC shapes for CO_2, even differentiating by geographical areas and by estimation techniques (Martinez-Zarzoso and Morancho, 2004; Vollebergh *et al.*, 2005; Cole, 2003; Galeotti *et al.*, 2006). Although the evidence is patchy, that is, heterogeneous across studies (which use different data with respect to time span and countries), there is some EKC evidence for CO_2 emerging for the OECD countries. This is counterbalancing other rather pessimistic views of no TP and a fragile EKC hypothesis (Harbaugh *et al.*, 2002; Millimet, List and Stengos, 2003).[6] Thus, the evidence is far from conclusive and continues to grow based on ongoing research aimed mainly at verifying the robustness of results across different models. We would agree, therefore, that a 'best' model for analysing EKC does not exist. In addition, at a certain level of advanced analysis, statistical 'fit' comparisons across models are harder to implement. A consolidated assessment of results is still underway; critical points and heterogeneity of outcomes across models are currently being tackled. Finally, there is often a lack of policy relevance given the nature of data and the objectives of analyses. Here, we aim to check robustness across different models, in order to provide results that will inform policy. We briefly critique the more recent analyses, focusing on work that deals with dynamics and structural heterogeneity in panels.

There is a series of papers providing empirical evidence, that exploit flexible panel parametric specifications and non-parametric methods. Martinez-Zarzoso and Bengochea-Morancho (2004) analyse CO_2 data for the period 1975-1998, for 22 OECD countries, by applying the PMG estimator. The evidence favours an N shape for the majority of OECD countries and an EKC inverted U shape for the less developed countries. The range of implied TPs is nevertheless too wide to lead to solid conclusions. Within the studies focusing on OECD, Cole (2005) applies the heterogeneous Swamy random coefficients estimator and concludes that the income-pollution relationship varies widely across countries. This suggests that the assumption of constants coefficients across countries in the traditional fixed-effects specification is inappropriate.

Recent developments in the literature test the robustness of the EKC hypothesis using either flexible parametric specifications or partially or fully non parametric models, or by looking at the cointegration properties of CO_2 time series; they have produced mixed results. 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 TPs within the observed income ranges; nevertheless, the null hypothesis of slope homogeneity is strongly rejected by the data. Dijkgraaf and Vollebergh analyse sample of 24 OECD countries for 1960-1997. The most striking result is that time series analysis provides a different picture

[6] Wagner (2006) and Muller Furstenberger and Wagner (2007), highlight various drawbacks from theoretical and empirical points of view, and question EKC evidence, finding no inverted U shape for CO_2 in their analyses of a balanced panel dataset of 107 countries over 1986-1990. Galeotti et al. (2006) are rather sceptical about EKC and test the robustness of the EKC hypothesis, analysing CO_2 series. They take as starting point the mixed evidence on EKC, showing first that the evidence seems not to depend on the source of the data (IEA or other), and that reasonable TP emerge for OECD countries (taken as a whole).

from heterogeneous panels. Only five out of 13 countries that show evidence of EKC dynamics present coherent results in the two frameworks.[7]

Vollebergh *et al.* (2005) explore various parametrical and non parametric specifications for a CO_2 dataset of OECD countries and find that EKC shapes are quite sensitive to the degree of heterogeneity in the panel estimations. Parametric models generate EKC shapes with quite low TPS, while the evidence is less robust from semi-parametric estimations. The non-parametric setting demonstrates the necessity to incorporate heterogeneity, which leads to the exploration of single country specific time series, and suggests caution in interpreting panel based EKC outcomes if they do not in some way address the heterogeneity issue. The existence of an EKC curve in cross country international frameworks such as OECD country based analyses, may depend on the balance between high income countries showing an inverted U shape dynamics and high income countries that present a still positive elasticity of emissions with respect to income. The role of semi-parametric and non-parametric EKC estimations is tackled by Azomahou *et al.* (2006), who use CO_2 data for 1960-1996 for 100 countries. They find that EKC shapes arise when a parametric panel model is used, but that a monotonic relationship emerges in both the non-parametric settings and the first difference regressions, as in the semi parametric analysis of Bertinelli and Strobl (2005).

On the basis of recent theoretical and empirical developments, we maintain that EKC analysis, is a useful tool for investigating income-environment relationships[8]. In light of recent developments, we argue that, with the increased time dimension of the panel, the choice of a more heterogeneous estimator may be preferable (Pesaran and Smith, 1995; Pesaran *et al.*, 1999; Hsiao *et al.*, 1999).

3. Model specification, estimation and data

3.1 Specification

Following the EKC and IPAT related literatures, and the main EKC oriented studies (e.g. Cole 2005; Stern, 2004), the per capita CO_2 emissions from a country i in period t is modelled as a function of per capita GDP, with both variables expressed in logarithms:

$$(1) \qquad y_{it} = f\left(x_{it}\right)$$

[7] They also point out that for some pollutants, such as CO_2, lack of homogeneity is not surprising, given the trends in international specialisation, differences in local features and the lack of strongly coordinated policies at least at international level.

[8] New studies may regards: analysis of single country panel dataset where within country heterogeneity (region-based) is exploited (List and Gallet, 1999, Carson *and* McCubbin 1997), the inclusion of key explanatory variables in the core EKC model, such as trade factors, which have been increasingly studied (Frankel and Rose, 2005; Cole at al., 2006;), energy factors (Aldy, 2006), spatial econometric techniques relevant for SOx (Maddison, 2005), semi or full non-parametric setting, including Bayesian approaches (Vollebergh *et al.*, 2005; Galeotti *et al.*, 2006; Azomahou et al., 2006; Mazzanti *et al.*, 2009).

In order to allow for a non-linear/non-monotonic relation, we employ a (parametric) quadratic specification. Thus, the long-run environmental degradation-income relationship is given by:

(2) $$y_{it} = \theta_{0i} + \theta_1 x_{it} + \theta_2 x_{it}^2 + \varepsilon_{it}$$

$$i = 1, \ldots N, \quad t = 1, \ldots, T$$

where y_{it} is the logarithm of CO_2 emissions per capita, x_{it} is the logarithm of per capita GDP, α_i is individual effects and ε_{it} is the error term.

Similar to many other studies (Azomahou *et al.*, 2006), we do not control for other possible determinants of CO_2 emissions, such as energy prices or technological change. Based on the present analysis, their investigation should be the subject of future research. There are several reasons for this specification. The first is data availability over long time series in terms of additional explanatory variables. Second, this specification allows for a greater comparability with existing studies. The third reason is more econometrically-oriented: although a specification that excludes other determinants of CO_2 emissions is not appropriate for measuring ceteris paribus the impact of GDP on CO_2 emissions, this kind of econometric specification is very useful for capturing the global effects of GDP on CO_2 including the indirect effects linked to the omitted variables which are correlated with GDP. Moreover, since we are not interested in obtaining the best prediction for CO_2, additional explanatory variables not correlated with GDP are irrelevant.

3.2 Data and samples

We focus on the developed regional areas that have been leading the climate change policy debate and were associated to Kyoto targets in 1997. We adopted the following samples' composition: (a) Australia, Canada, Japan, New Zealand, Norway, U.S.A. (The 'Umbrella group'); (b) Belgium, Denmark, Finland, France, Germany, Netherlands, Sweden, U.K. (EU North); (c) Austria, Greece, Ireland, Italy, PORTUGAL, SPAIN (EU 'south')[9].

Data on emissions are from the database on global, regional, and national fossil fuel CO_2 emissions prepared for the US Department of Energy's Carbon Dioxide Information Analysis Center (CDIAC). For our study, we use the subset of emissions data that matches the available time series on GDP per capita[10] on the basis of joint availability, series continuity, and country definitions. This resulted in a

[9] Note that the groups are homogeneous in terms of policy perspectives on climate changes. Some Umbrella countries have finally ratified the Kyoto protocol, which nevertheless is only the first step to addressing climate change at global level. The EU countries have all ratified the protocol, and now have different views on the post Kyoto phase and on the EU objectives of reducing emissions by 20% by 2020, a target led by EU north. Finally, for economic development motivations, some southern and poorer countries such as Greece, Spain, and Portugal were/are associated to Kyoto targets allowing increases of emissions around 20-30%.

[10] Data on GDP per capita in 1990 International 'Geary-Khamis' dollars are from the database managed by the OECD.

sample of 109 countries for the period 1960-2001, from which we extracted the countries of interest for our study. Table 1 summarises the main variables used and the descriptive statistics.

3.3 Panel estimators

The increased time dimension of panel data has generated new lines of research. A first strand of literature exploits panel data with time series procedures developed to deal with non-stationarity, spurious regression and cointegration (Kao and Chiang, 2000; Phillips and Moon, 1999). Another line of research developed both within and outside the framework of non-stationary panels concerns cross section dependence (Bai and Ng, 2004; Pesaran, 2007; Moon and Perron, 2007; Driscoll and Kraay, 1998). Finally, there is a third strand of literature that rejects the slope homogeneity implicit in the use of a pooled estimator, in favour of estimators allowing for individual slopes (Pesaran and Smith, 1995; Hsiao *et al.* 1999).

We begin by assessing the (sensitivity of) results, and model performance, across the following five 'homogeneous estimators' (Table 2): Least Square Dummy (LSD) estimator (FEM) allowing for individual fixed effects, as basis; then the Dynamic ordinary least squares (DOLS) estimator for the cointegrated panel data regressions (Kao and Chiang, 2000; Saikkonen, 1991); the PMG estimator proposed by Pesaran *et al.* (1999) which can be considered as an 'intermediate' estimator since it allows intercepts, short-run coefficients and error variances to differ freely across cross-sections while holding long-run coefficients the same,[11] the Driscoll-Kraay (DK) (1998) non-parametric estimator, which corrects the variance-covariance matrix for the presence of spatial as well as serial correlation and can be viewed as a variant of the Newey and West (1987) time series covariance matrix estimator; the GLS estimator of the Seemingly Unrelated Regressions (SUR) specification proposed by Zellner (1962) allowing cross section correlation via the individual error terms; and finally the Dynamic SUR (DSUR) which takes account of cross sectional correlation in a panel cointegrated framework (Mark *et al.*, 2004).

The first three estimators (FEM, DOLS, PMG) assume that all cross-section units are independent. In many cases, this assumption is clearly unrealistic from both economic and econometric points of view. First, the independence assumption is often at odds with economic theory. For instance, according to many economic models, agents tend to interact within and between cross-sections. Second, spatial dependence on unobservable factors could occur due to the presence of unobserved common factors. In these cases, standard techniques that do not take account of this dependence would yield inconsistent estimates of the parameter standard errors, producing incorrect inference and test statistics. Consequently, in order to correct for the presence of cross-sectional dependence, we also employ the last three estimators (DK, SUR, DSUR). We implement several tests of cross section

[11] However, a limitation of such approaches is that they assume that all cross section units are independent. For our multi-country samples, this assumption would be questionable. Therefore, we also use estimators allowing for cross sectional correlation.

independence[12] and in all cases they strongly reject the null hypothesis that the errors are independent across countries.

All these estimators allow individual intercepts but common slopes. Although the increase in the time dimension allows us to reject the slope-homogeneity implicit in pooled estimators, there are some features that render homogeneous estimators quite attractive. For example, Baltagi *et al.* (2000, 2002, 2004), find that homogeneous estimators have generally better forecasting[13] performance than their heterogeneous counterparts - mostly due to the simplicity, parsimony and stability of the parameter estimates.

Some authors suggest the use of heterogeneous estimators. For example, Baltagi *et al.* (2004) find that the superior forecasting performance of the homogeneous estimators is not a general result since both shrinkage estimators and the hierarchical Bayes estimator perform very well. There is another view that the use of heterogeneous estimators is related to the possible heterogeneity bias associated with the use of pooled estimators. As pointed out by Hsiao (2003), if the true model is characterised by heterogeneous intercepts and slopes, estimating a model with individual intercepts but common slopes could produce the false inference that the estimated relation is curvilinear. Empirically, this situation is more likely when the range of the explanatory variables varies across cross-sections. This situation corresponds to our empirical framework where: i) per capita GDP presents high variation across countries, ii) the different groups of countries cannot be characterised by a common slope and, consequently, there is a high risk of estimating a false curvilinear relation when using homogeneous estimators.

Next, we apply the five heterogeneous estimators (Tables 3-5). First, the Swamy (1970) random coefficient GLS estimator, which is a weighted average of the individual least squares estimates where the weights are inversely proportional to their variance-covariance matrices. This is used as a 'benchmark'. Then we apply and compare the Mean Group (MG) estimator proposed by Pesaran and Smith (1995) for dynamic random coefficient models. It is defined as the simple average of the OLS estimators relative to the individual equations expressed in ARDL; the hierarchical Bayes approach (Hsiao *et al.* 1999) which makes use of Markov Chain Monte Carlo methods via Gibbs sampling. Hsiao *et al.* (1999) show that this is asymptotically equivalent to the MG estimator; the shrinkage estimators described in Maddala *et al.* (1997), that is, the Empirical Bayes and the Iterative Empirical Bayes estimators. The parameter estimates are weighted averages (depending on the parameter variance-covariance matrices) of the pooled estimate and the individual time series estimates. Thus, the individual estimates are 'shrunk' toward the pooled estimate.

---

[12] The Lagrange multiplier approach of Breusch and Pagan (1980), the CD test of Pesaran (2004) and the Frees's (1995, 2004) statistics.

[13] Forecasting-oriented studies include Auffhamer and Carson (2008) and Schmalensee et al. (1998) among others.

4. Empirical evidence

We present evidence first comparing the long run EKC dynamics of the three groups of countries, in order to highlight differences in shapes and eventual TP across different panel data models. Policy implications may derive from implicit considerations on the factors that differentiate the three groups. Secondly, in order to add an explicit policy flavour, we test through structural break analysis whether *policy events* such as the 1992 Climate convention that gave birth to Kyoto and the 1997 Kyoto itself have affected the long run dynamics. We also test the presence of other structural breaks affecting the emission-income relationship. We believe that the 1992 turning point may be even more relevant since it is a threshold that distinguishes from countries that began policy actions even in the period preceding effective Kyoto convention (and the country ratification) and countries that waited Kyoto or beyond to take action.

4.1 EKC structural long run dynamics

Figures 1–3 depict the relationship between CO_2 and income for the three samples. We provide real data, and the curve fitted (non-parametrically) by robust locally weighted scatter plot smoothing (*lowness*). The relationship is clearly monotonic for the Umbrella group and for EU-South but shows an inverted U shape for EU-North countries. It should be noted that, while in some countries this inverted U-shaped pattern is symmetric, in others there is a non-symmetric pattern since the upward-bending portion of the curve does not swing back to the initial level of CO2 per capita.[14]

Our evidence is mainly concerned with comparison of 'homogenous', and 'heterogeneous' panel estimators, with the emphasis on cross sections correlation and adjustment dynamics.[15] As before, we examine six homogenous panel estimators (FEM as benchmark specification and DOLS,[16] PMG,[17] DK,[18] SUR[19] and DSUR[20]) and 5 heterogeneous based estimators (Swamy, MG, Empirical Bayes, Iterative Empirical Bayes, Hierarchical Bayes). For each specification modelled, we examine the three samples of countries in terms of carbon-income shape (elasticity) and eventual EKC TP, assessing whether this TP is within or outside the range of observed values.

---

[14] We present the results obtained using panel data regression approaches. They show the advantages of capturing the indirect effects linked to the omitted variables correlated with GDP. Moreover, they show some comparative advantage with respect to non-parametric panel approaches such as are used by Azoumahou et al. (2006). On the one hand a non-parametric panel approach allows for a free functional form; on the other hand, the parametric methods we employ allow for slope heterogeneity, adjustment dynamics and cross sectional correlation which are at least as relevant as functional form.

[15] Auffhammer and Carson (2008) in their forecasting oriented analysis point to the necessity of moving ahead from 'popular static' EKC towards dynamic models and specifications that account for spatial dependence.

[16] Implemented specifying a 0 lead and 2 lags. Results do not substantially differ if leads and lags change.

[17] The order of the auto regressive and distributed lag components were chosen using a general-to-specific procedure.

[18] The maximum lag considered in the autocorrelation structure (L) is set equal to 1. Alternative values of L (2, 3, 4) provide similar strand error estimates.

[19] Constraining the slope coefficients to be equal across equations while allowing for different intercepts.

[20] As for DOLS, it was implemented specifying 0 leads, 2 lags, and individual FE. Also, in this case, results do not differ if leads and lags change.

In relation to the first homogenous estimators, we note that the baseline FEM shows that quadratic specifications are significant for all the analysed cases, while the cubic specifications are not.[21] Nevertheless, the evidence is different across groups: while the TP for EU north is within the range of observed values ($13,000) this is not the case for the Umbrella group and EU south, which show similar (slightly higher for EU south) TPs , around $45,000-50,000 per capita.[22]

Inverted U shapes with a TP within the observed values for the EU-north group and outside the observed values for the Umbrella and EU-south groups, apply also to the other homogeneous estimators.

The DOLS estimator with 2 lags and no leads provides similar results to those from the FE specification and similar estimated TPs. DOLS assuming 0,1; 1,1; 1,2 (leads, lags) show low estimate variability, with an estimated TP for EU north stable at around $11,000 and for the Umbrella and EU south groups always outside the observed range of observations.

Introducing a certain degree of heterogeneity, as in the PMG estimator, and taking account of cross sectional correlation (DK, SUR, DSUR), do not modify the picture substantially. It should be noted, however, that while the TP estimate for pro-Kyoto countries is very stable across the different methods, allowing for cross-country correlation or for a limited degree of heterogeneity provides lower estimates of the quadratic specification and higher TPs, well outside the range of observations.[23]
To summarise the evidence from homogeneous specifications, apart from the differences in TP for the Umbrella and EU south groups, indicating non-existence of a robust EKC shape, the evidence for EU north is statistically and economically robust and is associated to EKC TPs in the range $11,000 to $14,000 per capita.

Comparison of the five heterogeneous panel data models presents slightly different evidence, which provides insights into economic and methodological perspectives.

The 'baseline' specification is the well known and extensively applied Swamy procedure which takes account of slope heterogeneity (Cole, 2005). The specification does not drastically modify the evidence presented above, but reveals other factors. For example, both the Umbrella and EU south groups, which showed an EKC shape with TPs outside the range, are now consistent; they do not present bell shapes, but demonstrate linear relationships between income and CO_2 emissions. Elasticity is slightly lower than 0.5, which is a sign of *relative delinking* in the dynamics of these countries, at least based on the 'group average'. EU north shows evidence of absolute delinking, with a TP of around $13,000.

---

21 Here, and subsequently, cubic specifications (terms) are never statistically significant, as expected. Figures 1-3 make it clear that for most countries the relevant test is whether or not a TP exists and also whether it is significantly robust and within the range of observed values.
22 The maximum value for income per capita is $28,129 per capita for the Umbrella group, $23,160 for EU north and $23,201 for EU south.
23 Note that the DC approach substantially decreases the standard error estimates.

The different evidence is worth noting since it highlights that all homogenous panel estimators, although in our case not showing robust EKC shapes from an economic point of view, tend to erroneously (see figures 1-5) capture output as a non-linear path. This quadratic trend may be the result of our not taking account of heterogeneity in income-environment relationships for certain groups of countries. Checking for outliers or 'non average' situations could modify the picture in homogeneous settings. However, in focusing our analysis on structural heterogeneity, we are providing an 'average' picture of 'single countries stories' for income-environment dynamics.

In terms of other heterogeneous based estimators, we note that the outcomes of the MG model and the Swamy procedure are very similar.

For the Bayesian approaches, we focus on empirical Bayes, iterative Bayes and hierarchical Bayes estimators. The first method for dealing with income environment curves shows results that are very similar to the 'baseline' represented by Swamy: elasticities for the Umbrella and EU south groups are around 0.46, and the TP for EU north is around $13,000. The stability of outcomes across models is stronger for heterogeneous than homogeneous models, which present some (not substantial) variability across specifications in terms of the estimated coefficients. Application of iterative empirical Bayes re-confirms this, with only very minor changes to the estimated coefficients and overall evidence.

Hierarchical Bayes is the only situation when an EKC emerges, but for anti-Kyoto countries, the quadratic terms are very low and the estimated TPs are well above the range of observed values. Instead, the TP for EU north is fairly consistent with the TPs in heterogeneous models, showing again coherency across models as far as EU north countries are concerned.

To sum up, the set of heterogeneous based estimators, Bayesian or not, provide robust evidence of an EKC for the EU north countries and only relative delinking for the other two groups. We note that the consistency of estimates across models (level of the coefficients) is stronger for heterogeneous models, which present lower variability. Also, they show that tackling heterogeneity using specific tools provides a clearer understanding of the income-environment relationship, although we can also highlight that the differences for the group showing EKC shapes (EU north) are slight even when comparing homogeneous and heterogeneous models. Overall, then, our evidence is very robust. We can be confident that the shapes and TPs we estimated are representative of the real phenomenon.

1.

2. 4.2 Evaluating 'policy events' in the climate change international arena

3. We now assess the impact of a *postulated policy event* on the carbon-income relationship. The 'intervention analysis' developed by Box and Tiao (1975) is the methodology of reference. Some

previous studies have successfully applied this methodology in modelling the economic effect of public policies[24].

In order to test the hypothesis that the occurrence of the 1992 UN Framework Convention[25], and the consequential 1997 Kyoto protocol, has modified the relation between emissions and economic development, the following model is specified:

(3) $$y_t = f(\mathbf{x}_t, \boldsymbol{\theta}) + g(\boldsymbol{\delta}, \boldsymbol{\omega}, \boldsymbol{\psi}, t)$$

where y_t denotes per capita CO_2 emission, $f(\mathbf{x}_t, \boldsymbol{\theta}) = \theta_0 + \theta_1 x_t + \theta_2 x_t^2 + \varepsilon_{it}$ corresponds to the EKC relation previously estimated, where x_t is per capita GDP. Finally, $g(\boldsymbol{\delta}, \boldsymbol{\omega}, \boldsymbol{\psi}, t)$ allows for some deterministic effects of time t, the effects of some exogenous variables, $\boldsymbol{\psi}$, measured through the vectors of parameters $\boldsymbol{\delta}$ and $\boldsymbol{\omega}$. This can be modelled combining a step function with an exponential (or first order) transfer function:

(4) $$\psi_t = Step\_1993_t = \begin{cases} 1, \text{ if } t \geq 1993 \\ 0, \text{ otherwise} \end{cases}, \qquad g(\boldsymbol{\delta}, \boldsymbol{\omega}, \boldsymbol{\psi}, t) = \frac{\omega}{1 - \delta \mathrm{B}} \psi_t$$

4.

5. where B is the backward shift operator such that $\mathrm{B}^i y_t = y_{t-i}$ .The magnitude of the impact that occurred after 1992 (alternatively 1997) is given by ω_1 and δ_1 is the rate of decay of the variation. When $\delta < 1$ the series will reach a new steady state and the steady state gain is $\omega / (1 - \delta)$, while when $\delta = 1$, a step change in the input produces a ramp function in the output. Finally, $\delta > 1$ will produce an exponential pattern decay. Alternatively, a gradual effect can be modelled using a 'ramp' function:

6.

7. (5) $$\psi_t = Ramp\_1993_t = \begin{cases} t - 1992, \text{ if } t \geq 1993 \\ 0, \text{ otherwise} \end{cases}, \qquad g(\lambda, \boldsymbol{\psi}, t) = \lambda \psi_t$$

[24] Sharma and Khare (1999), who assess the effectiveness of CO_2 pollution control legislation in India; Fomby and Hayes (1990), who examine the impact of redistributive policies in the US. Other relevant contributions include Lloyd et al. (1998), Murry et al. (1993) and Thompson and Noordewier (1992) who evaluate respectively anti-cartel policies, anti-drinking campaigns and incentive programs on automobile sales.

[25] This postulated break is coherent with the hypothesis that some countries may have acted as Kyoto early movers, on the basis of either/both the 1992 convention or/and even by before 1992 events.

8. where λ measures the magnitude of the change in the trend of the series. In that follows the ML estimation results are provided for both specifications and standard criteria (Akaike information criteria, AIC, Schwartze-Bayes criteria, SBC) are used in order to choose the one preferred.

9. The estimates in table 6 concern our three main groups (Umbrella, EU_NORD; EU_SUD) and highlight the preferred specifications that we comment on. Overall, the model based on the ramp function is preferred. The Umbrella[26] and EU-south groups are again homogeneous with regard to the income-environment relationship: first, EKC shapes present inverted U evidence with a turning point outside the range of observed values, secondly, the λ coefficients, representing the trend change, are significant, but positive in their signs (we refer also to fig. 6-7). The evidence highlights the fact that 1992 Framework Convention (and 1997 Kyoto) did not impact on the structural relationship. The positive sign is not unexpected insofar even recent data show that most EU south countries have experienced an increase in emissions in the 1998-2008 periods after Kyoto (EEA, 2008) and are still far from being compliant to reduction with respect to 1990 levels. The high growth (and low oil price) period that followed 1992 did not witness a significant break in the income-emission elasticity.

10. As far as EU north countries are concerned, a negative coefficient λ instead emerges in association to the trend change, with high statistical significance. Instead, it is worth noting that, following the application of an 'outliers selection procedure', a permanent shift occurred in the early eighty's (namely 1980 as key year) has also occurred. This has been modelled combining a step function with an exponential transfer function similar to eq. (4) (fig.8). Table 6 presents for EU north only regressions including the climate change and Kyoto conventions - 1992 and 1997 breaks - and the aforementioned change occurred after 1980, measured by the parameters $\omega 80$ and $\delta 80$, indicating respectively the magnitude of the impact and its decay pattern. The statistical 1980 break can refer to and be economically explained by the second oil shock (namely 1979), with all the consequential effects on the post-recession (1981-82) restructuration phase of advanced economies, beginning around early 80's (fig.9)[27], which is characterised by efforts towards higher energy efficiency and increasing environmental innovations (Jaffe et al., 1995).

11. At least looking at the picture until 2001, it seems that the absolute delinking experienced by Northern EU countries is attributable both to path-breaking policy events such as the 'environmental climate change conventions', and the consequential Kyoto protocol, and to exogenous events such as the 'Iranian revolution' and associated second oil price shock with the following recession of early 80's, with a consequential restructuring of such economies on more energy/environmental efficiency basis. Along a temporal dimension, the climate change political emphasis emerging in the 90's – in presence

[26] A temporary change relative to the period 1983-86 has been detected and introduced in the model (tab. 6).
[27] We note that this 'outlier' analysis reveals a significant break only for EU north. This is coherent with our comments.

of another recession in 1992-93 - could partly descend from the oil shocks, in addition to increasing environmental awareness coherent with EKC framework. This evidence is nevertheless limited to Northern EU countries that appear to have taken earlier actions in terms of economy restructuring and environmental policy actions. This may be a key reason for their strong support of Kyoto policies, as most (innovative and composition effects related) efforts were already in place in 1997. Lagging or anti Kyoto countries face(d) larger investments regarding CO_2 reduction, though probably lower marginal costs of abatement. Both issues matter for the current political/negotiation agenda. The current economic crisis may change the political agenda towards green investments, though we note that contrary to the exogenous break we highlighted, is characterised by low oil prices which do not incentive environmental efficiency investments. Other motivations have to be found.

5. Conclusions

This study has provided new EKC evidence based on long panel data series and exploiting various advanced panel estimators. We focus attention on three groups of countries in the political economy arena related to Kyoto (and post Kyoto) frameworks: the Umbrella group led by the US, the EU north group, which is the most proactive in climate change issues, and the EU south group of countries, which have lower incomes per capita and generally lower level commitment to climate change. Our results are relevant from both an economic and a methodological point of view, and are useful for informing the post Kyoto negotiation rounds.

We find that the Umbrella and EU south groups, which are less in favour of stringent climate policies, have not experienced a 'carbon Kuznets curve' yet, as expected, that is absolute delinking, although there is evidence of relative delinking in the carbon-income relationship, with elasticities around 0.45-0.50. The EU north countries show robust EKC shapes across panel specifications. It should be noted that both homogeneous and heterogeneous panel models provide similar evidence, with minor differences across models. However, the latter seem to perform better, insofar as they capture the real shape of Umbrella and EU south countries' relationship, which is linear and not bell shaped with TPs outside the range. When structural heterogeneity is relevant homogeneous panels inevitably capture the average trends for the groups of countries considered, and are more likely to give bell-shaped relationships for output.

Tests on the relevance of exogenous policy events, such as the 1992 climate change convention and the 1997 Kyoto protocol provide further and complementary policy oriented evidence. Exogenous pat breaking 'policy events' appear to matter. The income-emission relationship is in fact affected by such events, at least for Northern EU countries that present EKC shapes over the period. The post 1992-93 period, characterised by high growth and low oil prices, was a preliminary arena where some countries take early actions in environmental/energy policy aimed at increasing the GDP efficiency.

We indeed find some signs that the absolute delinking associated to EU northern countries may largely depend on exogenous shocks occurred well before the environmental conventions of early 90's; some results suggest in fact that the early 80's oil price shock and recession, and following energy-economy restructuring on more environmental efficient basis, was probably a major event in determining a turning point. This group of countries took advantage of the oil shock to restructure the economy and took early actions for setting a 'green' technological competitive advantage. These pre Kyoto facts largely explain their strong commitment towards climate change, as they are better positioned and already on the track. Given the sunk costs of investments, economies of scale and complementarity between green and standard innovation investments, such countries could lead the post Kyoto phase as well, after being mostly compliant with 1997 Kyoto targets. The reason for their higher commitment to Kyoto principles lie in the (social and policy) choice to acknowledge the opportunities presented by climate change 'markets' (green products, environmental innovation) as a basis for new competitive advantage, based on the production of an (impure) public good such as carbon abatement, combined with economic gains for the economy. Being an early mover in the market may enable these advantages to be consolidated in the medium long run.

Nevertheless, it is worth noting that considerations of global economic efficiency should also put the weight of future abatement on advanced countries that have not reached a TP in the income-environment relationship and are not compliant. On average, these lagging countries have more scope for incremental efforts towards abatement of carbon emissions (among others figures, the current consumption of oil is around 26 barrels per capita in the US and 12 in the average EU, thus even lower in some northern EU countries; on a total energy perspectives respective figures are 60 vs 30 barrels per capita), and then presumably lower marginal costs under usual assumptions on abatement cost functions and technological conditions. Climate change negotiation and policy initiatives in future years will demonstrate whether countries currently lagging in terms of delinking and commitment to climate change policy, will be able to combine carbon abatement and the achievement of environmental (innovation and policy) competitive advantages to become the basis for a race to the top of the ranking, not, as opposite possible scenario, a divergence in emission/income trends.

References

Aldy J. (2006), Per capita carbon dioxide emissions: convergence or divergence?, *Environmental and Resource Economics*, vol.33, n.4, pp.533-55.

Anderson D., Cavendish W. (2001), Dynamic simulation and environmental policy analysis: beyond comparative statics and the EKC, *Oxford Economic papers*, vol.53, pp.721-46.

Andreoni J., Levinson A. (2001), The simple analytics of the environmental Kuznets curve, *Journal of Public Economics* vol.80, pp.269-86.

Arrow K., Fisher A. (1974), Environmental Preservation, Uncertainty and Irreversibility, *Quarterly Journal of Economics*, vol. 88, pp. 312-19.

Auffhammer M., Carson T. (2008), Forecasting the path of China's CO2 emissions using province-level information, *Journal of Environmental Economics and Management*, vol.55, pp.229-47.

Azomahou T., Laisney F., Phu Ngayen V. (2006), Economic development and CO_2 emissions : a non parametric panel approach, *Journal of Public Economics*, vol.90, pp.1347-63.

Bai, J. and S. Ng (2004), A Panic Attack on Unit Roots and Cointegration, *Econometrica*, vol. 72, pp.1127–1177.

Baltagi BH, Griffin JM, Xiong W (2000), To pool or not to pool: Homogeneous versus heterogeneous estimators applied to cigarette demand, *Review of Economics and Statistics,* vol.82, pp.117–126

Baltagi BH, Bresson G, Pirotte A (2002), Comparison of forecast performance for homogeneous, heterogeneous and shrinkage estimators: Some empirical evidence from US electricity and natural- gas consumption. *Economics Letters,* vol.76, pp.375–382

Baltagi, B.H., Bresson, G., Pirotte, A., (2004), Tobin q: forecast performance for hierarchical Bayes, shrinkage, heterogeneous and homogeneous panel data estimators, *Empirical Economics* 29, 107–113.

Bertinelli L., Strobl E. (2005), The EKC semi parametrically revisited, *Economic letters*, pp.350-57

Box G. E. P. and Tiao G. C. (1975). Intervention analysis with applications to economic and environmental problems, *Journal of the American Statistical Association*, 70, 70-92.

Brajer V., Mead R., Xiao F. (2008), Health benefits of tunnelling through the chinese EKC, *Ecological Economics,* vol. 56, pp. 674-684.

Breusch, T.S., and A. R. Pagan (1980), The Lagrange Multiplier test and its application to model specifications in econometrics, *Review of Economic Studies* 47, pp.239-53.

Brock W., Taylor S. (2004), The Green Solow Model, NBER working paper n.10557, NBER, Cambridge, MA.

Carson R., McCubbin R. (1997), The relationship between Air Pollution Emissions and Income: U.S. data, *Environment and Development Economics*, vol. 2, n. 4, pp. 433-450.

Chimeli A., Braden J. (2008), A capital scarcity theory of the EKC, *Environmental and resource economics*, forthcoming.

- (2005), Total factor productivity and the Environmental Kuznets curve, *Journal of Environmental Economics and Managemen*t, vol.49, pp.366-80.

Cole M.A. (2005), Re-examining the pollution-income relationship: a random coefficients approach. *Economics Bulletin*, vol.14, pp.1-7.

- (2003), Development, Trade and the Environment: How Robust is the Environmental Kuznets Curve? *Environment and Development Economics,* vol.8, pp.557-80.

Cole M.A., Rayner A.J., Bates J.M. (1997), The Environmental Kuznets Curve: an empirical analysis, *Environment and Development Economics,* vol.2, pp.401–416.

Cole M.A,, Elliott R., Fredrikkson P. (2006), Endogenous pollution haves: does FDI influence environmental regulations?, *Scandinavian Journal of Economics*, vol.108, pp.157-178.

Copeland B.R., Taylor M.S. (2004), Trade, growth and the environment, *Journal of Economic literature*, vol.42, p.7-71.

De Bruyn S., Van den Bergh J., Opschoor J. (1998), Economic Growth and Emissions: Reconsidering the Empirical Basis of EKC, *Ecological Economics,* vol. 25, pp. 161-75.

Dinda S. (2005), A Theoretical Basis for the EKC, *Ecological Economics*, vol. 53, n. 3, pp. 403-13.

- (2004), Environmental Kuznets Curve Hypothesis: a Survey, *Ecological Economics,* vol. 49, pp. 431-55.

Di Vita G. (2003), Is the discount rate relevant in explaining the EKC?, FEEM working papers, n.83, FEEM, Milan.

Dijkgraaf E., Vollebergh H. (2005), A test for parameter homogeneity in CO_2 panel EKC estimations, *Environmental and Resource Economics*, vol.32, n.2, pp.229-39.

Driscoll, J. C. and Kraay, A. C. (1998). Consistent covariance matrix estimation with spatially dependent panel data. The Review of Economics and Statistics, 80:549–560.

EEA, (2003), *Europe's environment: The third assessment*, Copenhagen: European Environment Agency.
- (2008), *Greenhouse gas emission trends and projections in Europe 2008*, Copenhagen: European Environment Agency.
Fomby, T.B., and K.J. Hayes. (1990). An Intervention Analysis of the War on Poverty: Poverty's Persistence and Political-Business Cycle Implications." Journal of Econometrics 43, 197±212.
Frees, E.W. (1995), Assessing cross-sectional correlation in panel data, *Journal of Econometrics* 69, 393-414.
Frees E.W. (2004), *Longitudinal and Panel Data: Analysis and Applications in the Social Sciences*, Cambridge University Press.
Frankel J., Rose A. (2005), Is trade good or bad for the environment? *The Review of economics and statistics*, vol.87, n.1, pp.85-91
Furstenberger G., Wagner M. (2007), Exploring the EKC Hypothesis: Theoretical and Econometric Problems, *Ecological Economics,* vol. 67, pp. 648-660.
Galeotti M., Lanza A., Pauli F. (2006), Reassessing the environmental Kuznets curve for CO_2 emissions: a robustness exercise, *Ecological Economics* vol.57, pp.152-163
Gelfand A.E., Smith A.F.M. (1992), Bayesian statistics without tears: a sampling-resampling perspective. *American Statistician* vol.46, pp.84-88.
Grossman G.M., Krueger A.B. (1995), Economic Growth and the Environment. *Quarterly Journal of Economics* May, pp.353-357
Halkos G. (2003), EKC for sulphur: evidence using GMM estimation and random coefficient panel data models, *Environment and development economics*, vol.8, pp.581-601.
Harbaugh W., Levinson A., Wilson D. (2002), Re-examining the empirical evidence for an environmental Kuznets curve, *The Review of economics and statistics*, vol.115, n.4, pp.1167-99.
Holtz-Eakin D., Selden T.M. (1992), Stoking the fires? CO_2 emissions and economic growth, NBER Working Papers 4248. NBER.
Hsiao C. (2003), *Analysis of panel data.* Cambridge University Press, Cambridge
Hsiao C, Pesaran MH, Tahmiscioglu AK (1999) Bayes estimation of short-run coefficients in dynamic panel data models. In: Hsiao C, Lahiri K, Lee L-F, Pesaran MH (eds) *Analysis of panels and limited dependent variable models.* Cambridge University Press, Cambridge, pp.268–296
Huang H.C., Lin S.C. (2007), Semi parametric Bayesian inference of the Kuznets hypothesis, *Journal of development economics*, vol.83, pp.491-505.
Kao, C., Chiang M.H. (2000), On the Estimation and Inference of a Cointegrated Regression in Panel Data, *Advances in Econometrics*, 15, 179-222.
Kelly D. (2003), On EKC arising from stock externalities. *Journal of Economic Dynamics and Control*, vol.27, n.8, pp.367-90.
Khanna, N., Plassmann F. (2007), Total factor productivity and the Environmental Kuznets Curve: A comment and some intuition, *Ecological Economics*, *63, 1*, *pp.54-58*.
Kim J. (2004), Growth of regional economy and income inequality: county level evidence from Florida, *Applied Economics*, vol.36, n.2, pp.173-183.
Lindley D.V., Smith A.F.M (1972), Bayes estimates for the linear model. *Journal of The Royal Statistical Society,* vol.34, pp.1-41.
List J.A., Gallet C.A. (1999), Does one size fits all?, *Ecological Economics*, vol.31, pp.409-424.
Lloyd, T., O. Morrissey and G. Reed, 1998. Estimating the Impact of Anti-Dumping and Anti-Cartel Actions Using Intervention Analysis, *Economic Journal*, 108, 458-76,
Jaffe A., Peterson S.R., Portney P.R., Stavins R. (1995), Environmental regulation and the competitiveness of US manufacturing: what does the evidence tell us? *Journal of Economic Literature* vol. 33, pp.132-63.
Jaeger W.K., van Kolpin V. (2008), The EKC from multiple perspectives, nota di lavoro 38.2008, wp series FEEM, Milan.
Maddala GS, Trost RP, Li H, Joutz F (1997) Estimation of short-run and long-run elasticities of energy demand from panel data using shrinkage estimator, *Journal of Business and Economic Statistics,* vol.15, pp.90–100
Maddison D. (2005), EKC: a spatial econometric approach, *Journal of Environmental Economics and management,* vol. 51, n.2, pp.218-30.

Managi S., Ranjan Jena P. (2008), Environmental Productivity and Kuznets curves in India, *Ecological Economics*, vol.65, pp.432-440.
Mark, N.C., M. Ogaki and D. Sul (2004), Dynamic Seemingly Unrelated Cointegration Regression, *Review of Economic Studies.*
Martinez-Zarzoso I., Bengochea-Morancho A. (2004), Pooled mean group estimation of an environmental Kuznets curve for CO_2, *Economics Letters,* vol. 82, pp. 121-126.
Martinez-Zarzoso I., Bengochea-Morancho A., Morales Lage R. (2007), The Impact of Population on CO_2 Emissions: Evidence from European Countries, *Environmental and Resource Economics*, vol.38, pp.497-512.
Mazzanti M., Musolesi A., Zoboli R. (2009), A Bayesian Approach to the estimation of EKC for CO_2, *Applied Economics*, forthcoming
Mazzanti M. Zoboli R. (2009), Environmental efficiency and labour productivity: trade-off or joint dynamics?, *Ecological Economics*, vol.68, 1182-94.
Mazzanti M., Montini A., Zoboli R. (2008), Economic dynamics, Emission trends and the EKC hypothesis. New evidence using NAMEA, *Economic system research*, vol.20, n.3, pp.279-305.
Millimet D., List J., Stengos T. (2003), The EKC: real progress or misspecified models? *The Review of economics and statistics*, vol.85, n.4, pp.1038-1047
Murray, J.P., Stam, A., Lastovicka, J.L., 1993. Evaluating an Anti-Drinking and Driving Advertising Campaign with a Sample Surveyand Time Series Intervention Analysis. Journal of the American Statistical Association. 88,50–56.
Moon, H.R. and B. Perron (2007), Efficient Estimation of the SUR Cointegration Regression Model and Testing for Purchasing Power Parity, *Econometric Reviews.*
Newey W.K. and West K.D. (1987), .A Simple, Positive Semi-definite, Heteroskedasticity and Autocorrelation Consistent Covariance Matrix., *Econometrica*, vol.55, pp.703.708.
OECD (2002), *Indicators to Measure Decoupling of Environmental Pressure from Economic Growth*, Paris, OECD.
Pasche M. (2002), Technical progress, structural change and the EKC, *Ecological Economics*, vol.42, pp.381-389.
Pesaran, M.H. (2004), General diagnostic tests for cross section dependence in panels, Cambridge Working Papers in Economics No. 0435, Faculty of Economics, University of Cambridge.
Pesaran, M.H. (2007), A Simple Panel Unit Root Test in the Presence of Cross Section Dependence, Journal of Applied Econometrics, 22, 265–312.
Pesaran, M.H., Smith, R. (1995), Estimating Long-run Relationships from Dynamic Heterogeneous Panels, Journal of Econometrics, 68, 79-113.
Pesaran MH, Shin Y, Smith R (1999) Pooled mean group estimation of dynamic heterogeneous panels. *Journal of the American Statistical Association* vol.94, pp.621–634.
Phillips P.C.B., Moon H.R. (1999), Linear Regression Limit Theory for Non-stationary Panel Data, *Econometrica*, vol. 67, 1057-1111.
Porter M., Van der Linde C. (1995), Toward a new Conception of the Environment-Competitiveness Relationship, *Journal of Economic Perspectives*, vol. 9, n. 4, pp. 97-118.
Prieur F. (2007), The Environmental Kuznets Curve in a World of Irreversibility, Nota di lavoro 57, Milan, FEEM.
Ranjan R., Shortle J. (2007), The EKC when the Environment Exhibits Hysteresis, *Ecological Economics*, vol.15, pp.204-215.
Roca J., Serrano M. (2007), Income growth and atmospheric pollution in Spain: an input output approach, *Ecological Economics*, vol.63, pp.230-42.
Roy N., van Kooten C. (2004), Another Look at the Income Elasticity of non Point Source Pollutants: a Semi Parametric Approach, *Economic Letters*, vol. 85, n. 1, pp. 17-22.
Saikkonen, P. (1991), Asymptotic Efficient Estimation of Cointegration Regressions, *Econometric Theory*, 7, 1–21.
Schmalensee R., Stoker T. Judson R. (1998), World Carbon Dioxide emissions 1950-2050, *The Review of economics and statistics*, vol.80, n.1, pp.15-27.
Selden D.H., Song D. (1994), Environmental Quality and Development: Is there a Kuznets Curve for Air Pollution Emissions?, *Journal of Environmental Economics and Management*, vol. 27, n. 2
Shafik N. (1994), Economic Development and Environmental Quality: An Econometric Analysis, *Oxford Economic Papers*, vol.46, pp. 757-73.
Shafik N., Bandyopadhyay (1992), Economic Growth and Environmental Quality: Time Series and Cross Country Evidence, World Bank policy research working paper 904, Washington D.C., World Bank.
Sharma, P., Khare, M. (1999), "Application of intervention analysis for assessing the effectiveness of CO pollution control legislation in India", Trans. Res. Part D, Vol.4, No. 6, pp 427-32 .

Smulders S., Bretscgher L. (2000), Explaining EKC: how pollution induces policy and new technologies, Tilburg University, Centre for Economic Research, mimeo.
Song T., Zheng T., Tong L. (2008), An empirical test of the EKC in China: a panel cointegration approach, *China Economic Review*, vol.19, pp.381-92.
Stern D.I. (2004), The rise and fall of the Environmental Kuznets curve. *World Development,* vol.32, pp.1419-38.
Swamy P. (1970), Efficient Inference in a Random Coefficient Regression Model. *Econometrica*, vol.38, pp.311-32.
Taskin F., Zaim O. (2000), A Kuznets curve in environmental efficiency: an application on OECD countries, *Environmental and Resource Economics*, vol.17, n.1, pp.21-36.
Thompson, P.A. and T. Noordewier, (1992). Estimating the Effects of Consumer Incentive Programs on Domestic Automobile Sales. *Journal of Business & Economic Statistics*, Vol. 10, No. 4, pp. 409-417.
Vollebergh H., Dijkgraaf E. (2005), A Test for Parameter Homogeneity in CO_2 Panel EKC Estimations, *Environmental and Resource Economics*, vol. 32, n. 2, pp. 229-39.
Vollebergh H., Dijkgraaf E., Melenberg B. (2005), Environmental Kuznets Curves for CO_2: Heterogeneity versus Homogeneity, Discussion Paper 25, Tilburg University, Center for Economic Research, Tilburg.
York R., Rosa E., Dietz T. (2003), STIRPAT, IPAT and ImPACT: analytic tools for unpacking the driving forces of environmental impacts, *Ecological Economics*, vol.46, pp.351-65.
Wagner M. (2006), The Carbon Kuznets Curve: a Cloudy Picture Emitted by Bad Econometrics?, working paper economic series 197, Wien, Institute for Advanced Studies.
Zellner, A. (1962), An Efficient Method of Estimating Seemingly Unrelated Regressions and Test for Aggregation Bias, *Journal of the American Statistical Association*, vol.57, pp.348-368.

Table 1- Descriptive statistics

	mean	s.d.	Min	max
Umbrella group				
CO_2 per capita	3.144921	1.393584	0.67	5.85
GDP per capita (GDPpc)	15,143.21	4,763.547	3,986.417	28,129.23
EU North				
CO_2 per capita	2.60875	0.5630643	.91	3.88
GDP per capita (GDPpc)	14,203.73	3,759.392	6,230.359	23,160
EU South				
CO_2 per capita	1.488294	0.6085014	0.25	3.05
GDP per capita (GDPpc)	10,215.44	42,65.277	29,55.836	23,201.45

T= 1950-2001; CO_2 per capita in t/pc; GDP per capita in 1990 International 'Geary-Khamis' dollars

Table 2 – Homogenous estimators: FEM, DOLS, PMG

Model	FEM						DOLS						PMG					
	coef.	t-stat.	coef.	t-stat.	coef.	t-stat.	coef.	t-stat.	coef.	t-stat.	coef.	t-stat.	coef.	t-stat.	coef.	t-stat.	coef.	t-stat.
Group of countries	Umbrella		EU north		EU south		Umbrella		EU north		EU south		Umbrella		EU north		EU south	
GDPpc (linear)	3.716	7.146	16.888	14.762	2.862	8.493	6.948	6.010	13.606	6.069	1.701	2.343	3.041	2.067	12.846	5.375	3.117	4.485
GDPpc (quadratic)	-0.173	-6.407	-0.890	-14.833	-0.132	-7.333	-0.316	-5.092	-0.731	-6.130	-0.081	-1.985	-0.126	-1.64	-0.687	-5.452	-0.152	-4.000
EKC shape	inverted U		inverted U		inverted U		inverted U		inverted U		inverted U		inverted U		inverted U		inverted U	
Turning point ($1995)	46,160.715		13,195.623		51,067.782		57,894.784		10,990.809		38,163.230		174,113.091		11,491.294		28,375.730	
Turning point range	out		in		out		out		in		out		out		in		out	

Table 3 –Estimators allowing for cross sectional dependence: DK, SUR, DSUR

Model	DC						SUR						DSUR					
	coef.	t-stat.	coef.	t-stat.	coef.	t-stat.	coef.	t-stat.	coef.	t-stat.	coef.	t-stat.	coef.	t-stat.	coef.	t-stat.	coef.	t-stat.
Group of countries	Umbrella		EU north		EU south		Umbrella		EU north		EU south		Umbrella		EU north		EU south	
GDPpc (linear)	3.716	5.97	16.888	9.96	2.862	4.87	3.072	15.133	15.202	26.165	2.498	13.287	3.253	5.667	10.996	6.062	3.337	4.654
GDPpc (quadratic)	-0.173	-5.23	-0.890	-9.89	-0.132	-4.14	-0.138	-12.54	-0.796	-25.67	-0.113	-11.30	-0.031	-4.613	-0.096	-5.979	-0.038	-4.211
EKC shape	inverted U		inverted U		inverted U		inverted U		inverted U		Inverted U		inverted U		inverted U		inverted U	
Turning point ($1995)	46,160.715		13,195.623		51,067.782		68,216.025		14,030.586		63,139.216		87,040.245		14,449.242		33,796.922	
Turning point range	out		in		out		out		in		out		out		in		Out	

DC: we set the maximum lag to be considered in the autocorrelation structure, l, equals to 1 (with l=2 or 3 we get similar results)

Table 4 – Heterogeneous estimators: Swamy, MG, Hierarchical Bayes

Model	Swamy						MG						Hierarchical Bayes					
Group of countries	Umbrella		EU north		EU south		Umbrella		EU north		EU south		Umbrella		EU north		EU south	
	coef.	t-stat.	coef.	t-stat.	coef.	t-stat.	coef.	t-stat.	coef.	t-stat.	coef.	t-stat.	coef.	t-stat.	coef.	t-stat.	coef.	t-stat.
GDPpc (linear)	0.473	4.778	17.492	4.135	0.464	6.705	0.475	3.006	12.262	4.966	0.436	4.955	3.600	36.327	17.494	201.080	2.178	25.326
GDPpc (quadratic)	…	…	-0.922	-4.229	…	…	…	…	-0.654	-5.070	…	…	- 0.163	-3.630	-0.922	-36.888	-0.088	-2.667
EKC shape	monotonic		inverted U		monotonic		monotonic		inverted U		monotonic		inverted U		inverted U		inverted U	
Turning point ($1995)			13,172.68						11,785.41				62,501.4		13,159.87		236,806.82	
Turning point range			in						in				out		in		out	

(…) means not included given not significance

Table 5 – Shrinkage estimators: Empirical Bayes and Iterative Empirical Bayes

Model	Empirical Bayes						Iterative Empirical Bayes					
Group of countries	Umbrella		EU north		EU south		Umbrella		EU north		EU south	
	coef.	t-stat.	coef.	t-stat.	coef.	t-stat.	coef.	t-stat.	coef.	t-stat.	coef.	t-stat.
GDPpc (linear)	0.473	4.827	17.470	4.330	0.465	6.838	0.473	4.876	17.287	4.791	0.465	6.838
GDPpc (quadratic)	…	…	-0.920	-4.319	…	…	…	…	-0.912	-4.800	…	…
EKC shape	monotonic		inverted U		monotonic		monotonic		inverted U		monotonic	
Turning point ($1995)			13,287.32						13,062.78			
Turning point range			in						in			

(…) means not included given not significance

Table 6 – Structural analyses on Policy events

Specification	θ_0	θ_1	θ_2	ω	δ	λ	TC8386	ω 80	δ 80	AIC	SBC
UMBRELLA											
Step_1993	-79.33(.00)	16.39(.00)	-.83(.00)	.013(.01)	1.02(.00)		-.06(.00)			-209.26	-198.98
Ramp_1993	-74.91(.00)	15.47(.00)	-.78(.00)			.013(.00)	-.06(.00)			-212.03	-203.34
Step_1997	-71.65(.00)	14.75(.00)	-.75(.00)	.04(.01)	.57(.02)		-.07(.00)			-201.86	-191.57
Ramp_1997	-66.66(.00)	13.70(.00)	-.69(.00)			.018(.00)	-.07(.00)			-204.88	-196.19
EU_SUD											
Step_1993	-49.95(.00)	10.29(.00)	-.52(.00)	.015(.03)	1.02(.00)					-179.53	-170.97
Ramp_1993	-47.99(.00)	9.86(.00)	-.50(.00)			.014(.00)				-185.75	-178.80
Step_1997	-45.00(.00)	9.18(.00)	-.46(.00)	.041(.04)	.61(.04)					-174.28	-165.72
Ramp_1997	-.43.00(.00)	8.73(.00)	-.43(.00)			.020(.00)				-179.72	-172.78
EU_NORD											
Step_1993	-5.15(.85)	.64(.91)	.002(.99)	-.01(.25)	1.22(.00)			-.09(.00)	.74(.00)	-140.51	-128.51
Ramp_1993	-5.29(.84)	.67(.90)	.0002(.99)			-.02(.01)		-.10(.00)	.72(.00)	-139.69	-129.40
Step_1997	-5.31(.84)	.68(.90)	.003(.99)	-.05(.06)	.81(.00)			-.09(.00)	.77(.00)	-142.73	-130.74
Ramp_1997	-5.28(.84)	.67(.90)	.0002(.99)			-.03(.00)		-.09(.00)	.77(.00)	-144.07	-133.79

p values in brackets

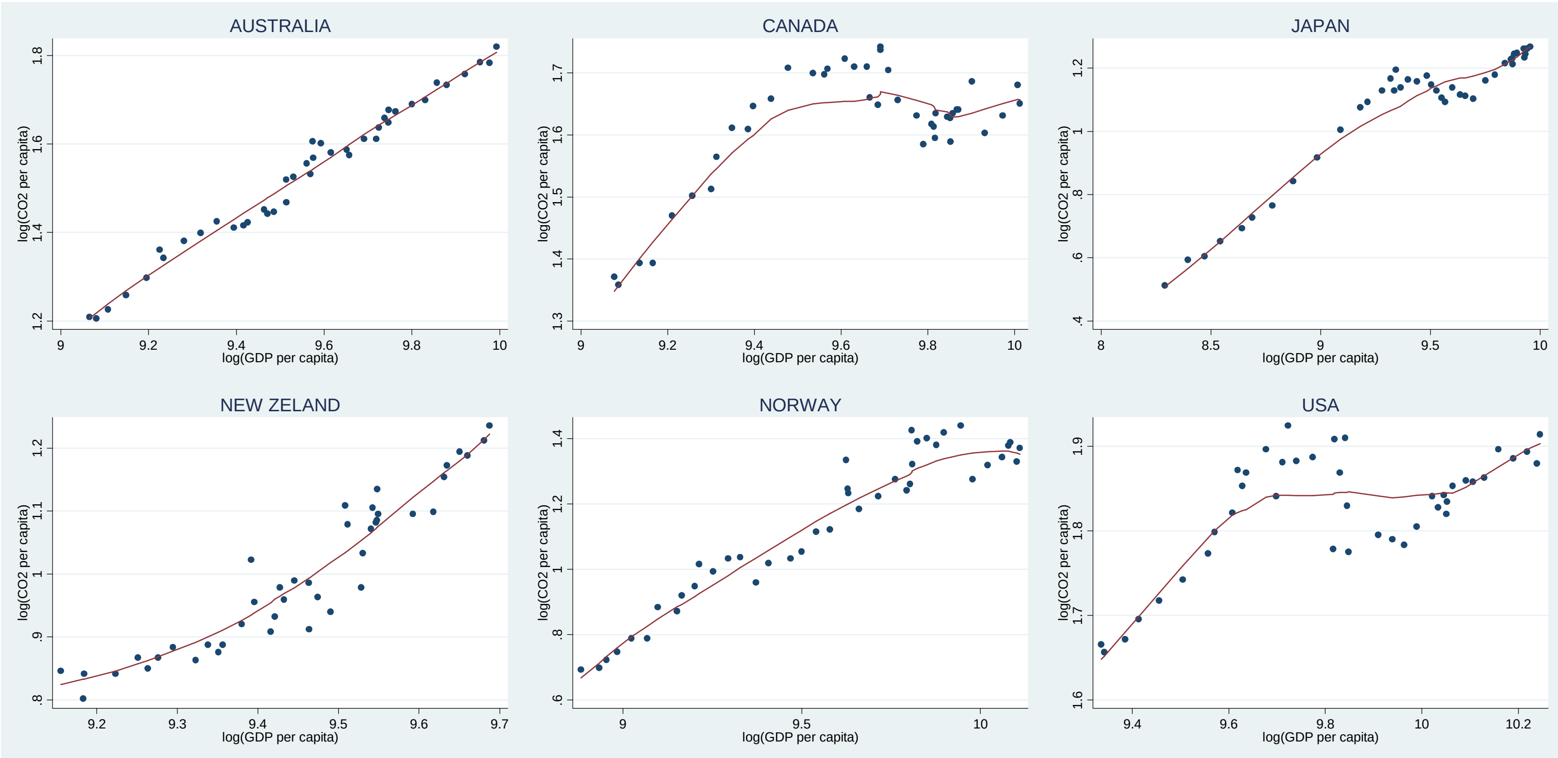

Figure 1. UMBRELLA countries (scatter : real values. Line : robust locally weighted scatterplot smoothing)

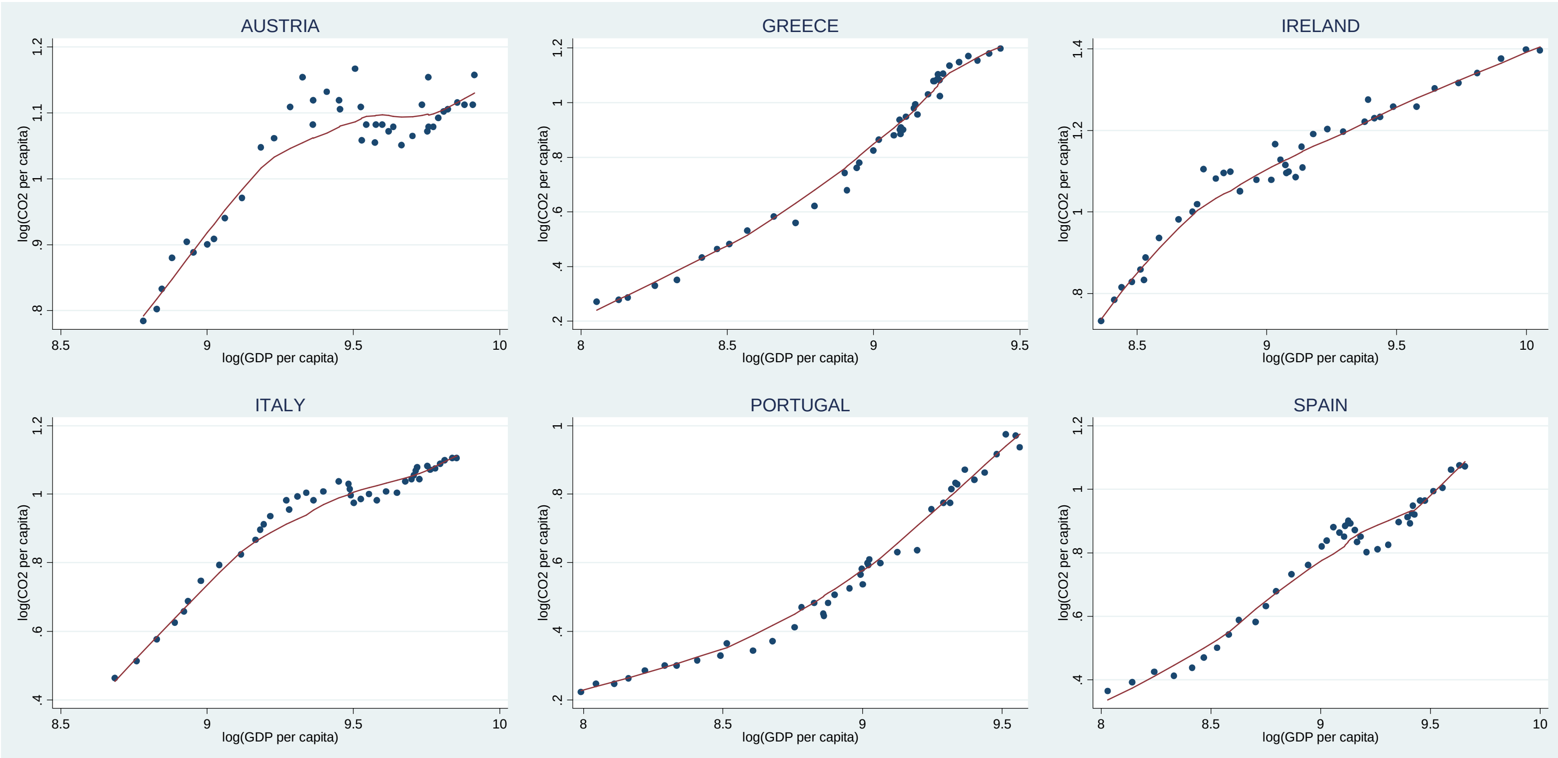

Figure 2. EU-SOUTH countries (scatter : real values. Line : robust locally weighted scatterplot smoothing)

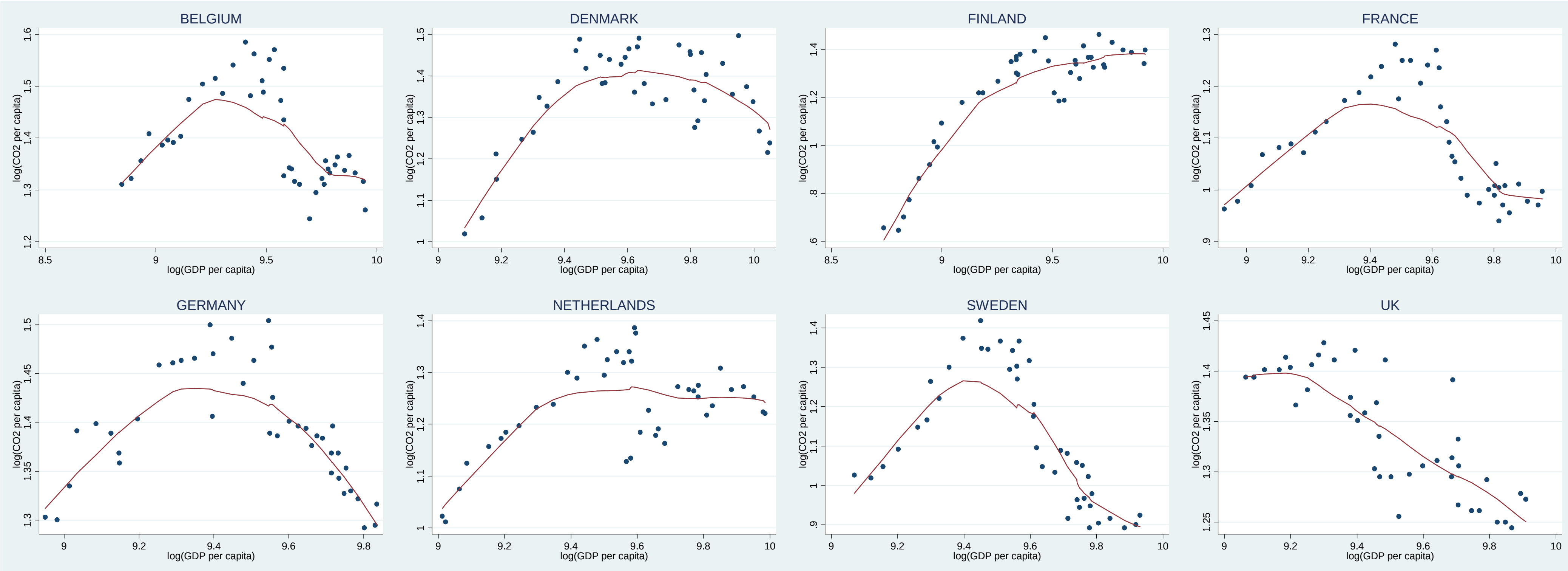

Figure 3. EU-NORTH countries (scatter : real values. Line : robust locally weighted scatterplot smoothing)

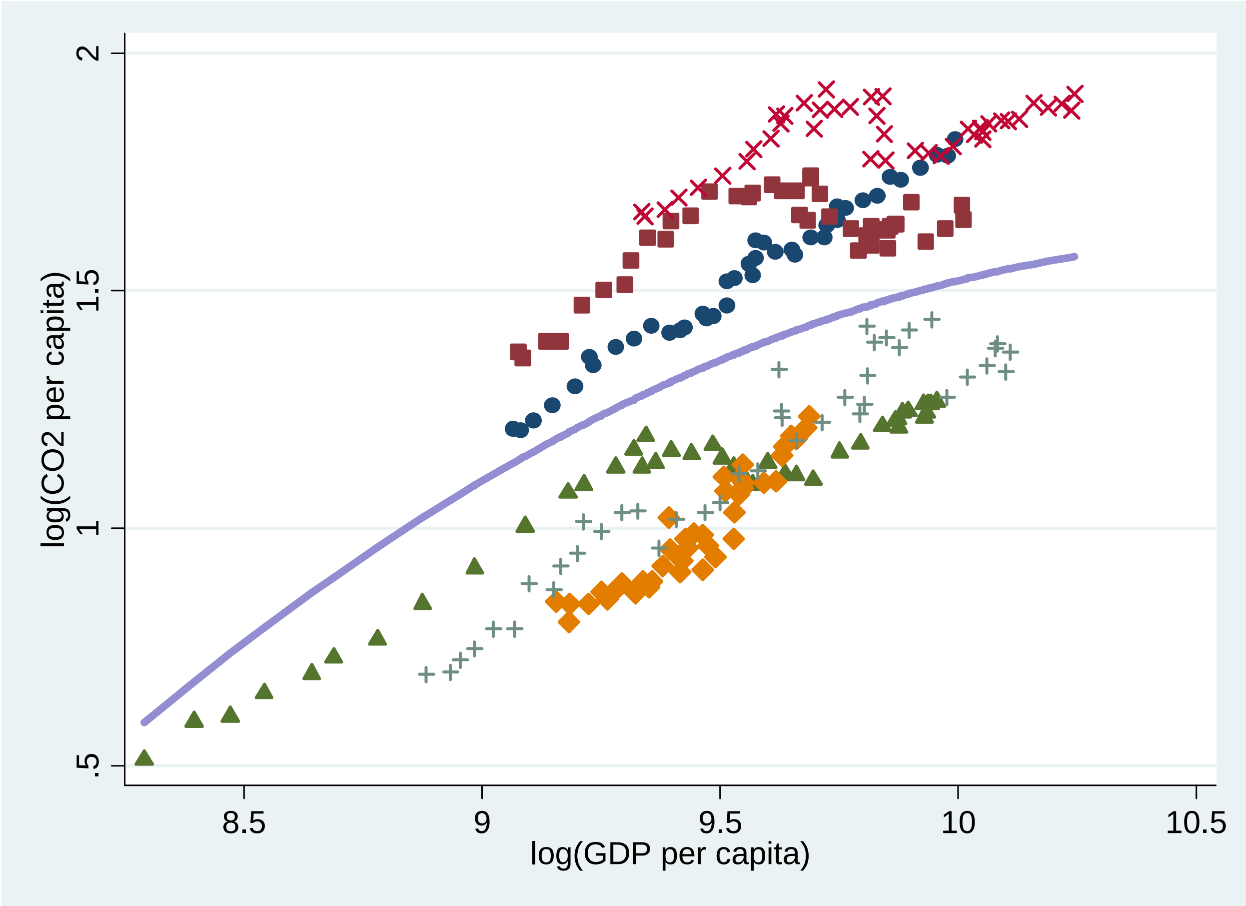

Figure 4. Umbrella countries: real and fitted values with homogeneous (FEM) regression
(scatter : real values. Line : fitted values)

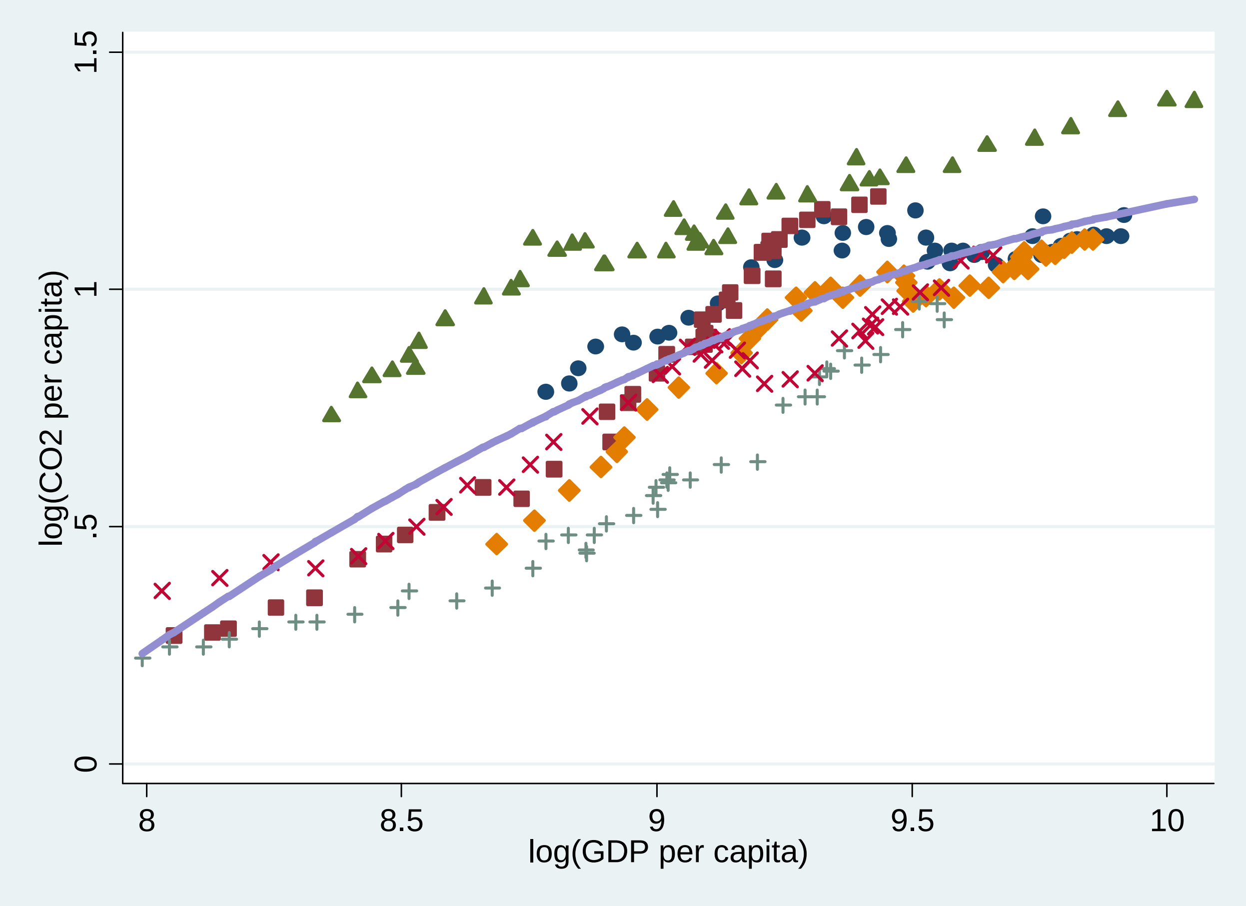

Figure 5. EU-SOUTH countries: real and fitted values with homogeneous (FEM) regression (Scatter : real values. Line : fitted values)

Fig. 6 – Real and fitted values, Umbrella

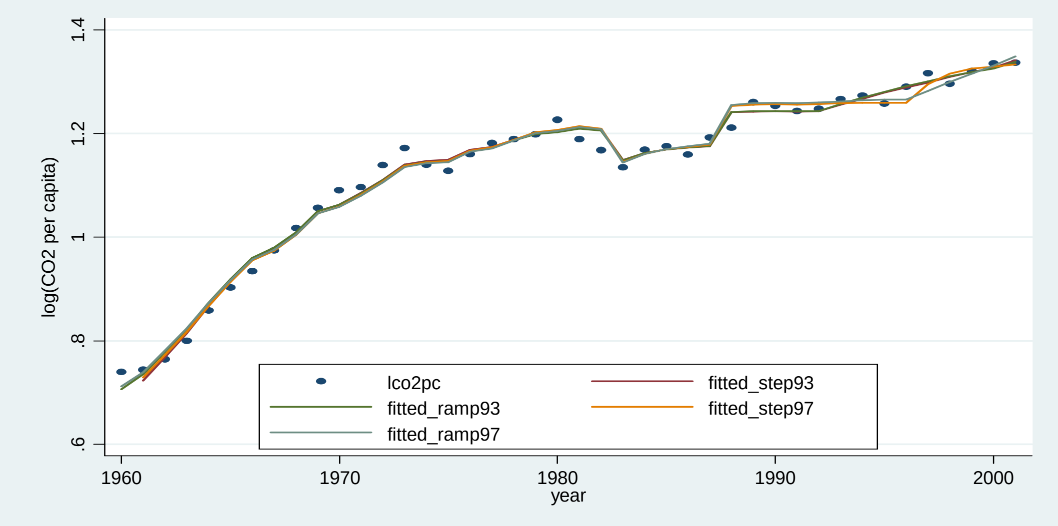

Fig. 7 - Real and fitted values, EU south

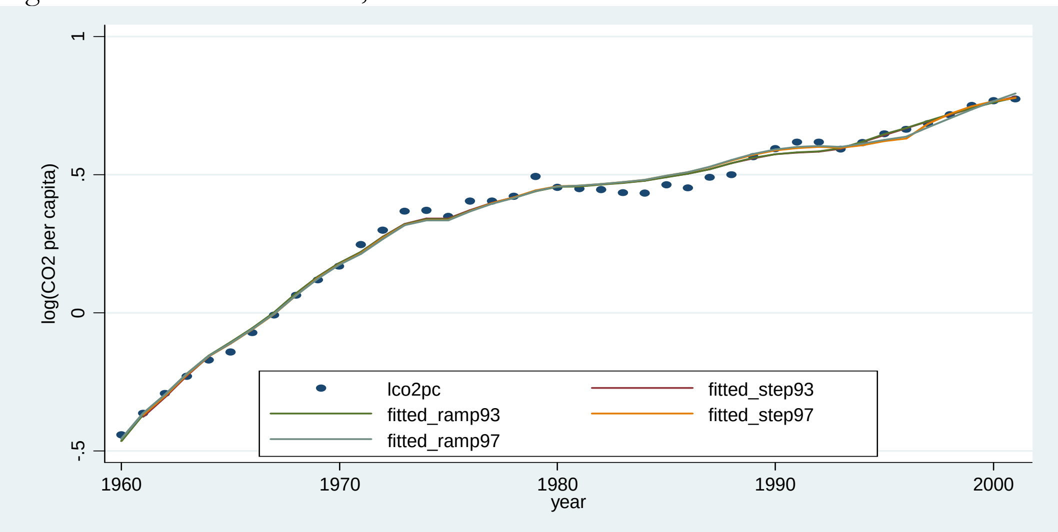

Fig. 8 – Real and fitted values, EU North

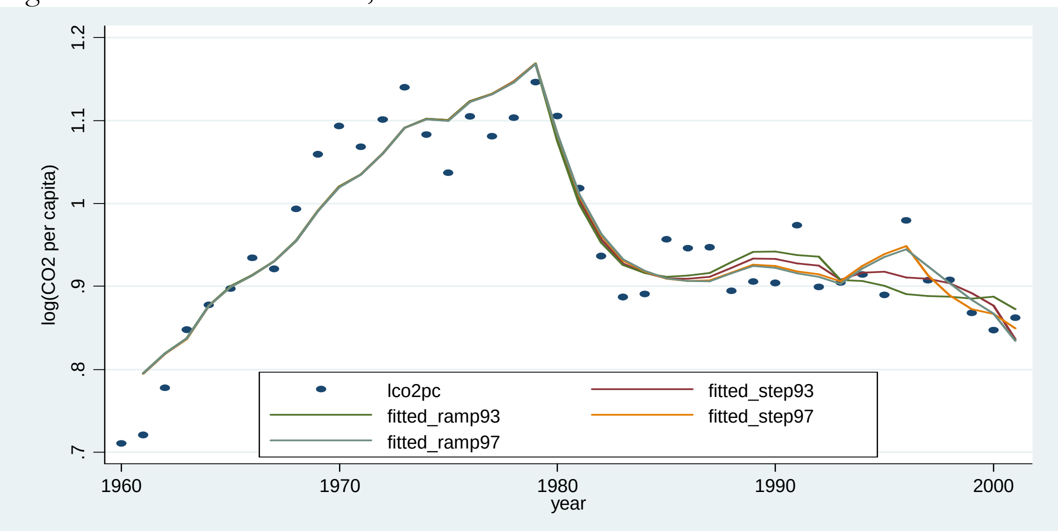

Fig 9 – CO_2 and GDP trends