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Leaders and laggards: why were some countries speaking stronger to carbon abatement?

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Long run income-carbon relationships and time related (policy) events

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Abstract

We study the eventual structural differences of climate change leading 'actors' such as Northern EU countries, and 'lagging actors' - southern EU countries and the 'Umbrella group' - with regard to long run (1960-2001) carbon-income relationships. Parametric and semi parametric panel models show that the groups of countries that were in the Kyoto arena less in favour of stringent climate policy, have yet to experience a turning point, though they at least show *relative delinking* in their monotonic carbon-income relationship. Northern EU instead robustly shows bell shapes across models, which seem to depend on time related (policy) events. *Time related effects* are more relevant than income effects in explaining the occurrence of robust Kuznets curves. The reaction of northern EU to exogenous policy events such as the 1992 climate change convention that gave earth to the Kyoto era, and even the second oil shock that preceded it in the 80's are among the causes of the observed structural differences.

Keywords: Carbon Kuznets Curves, Kyoto, long run dynamics, policy events, heterogeneous panels, cross-section correlation, semi parametric models, common time trends.

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1. Analysing carbon Kuznets curves in a policy-oriented perspective

Indicators of *decoupling*, or *delinking*, 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).

In this paper, the focus is on CO_2 emissions (CKC, Carbon Kuznets curves) which have been recognised as a major source of environmental pollution (Schmalensee *et al.*, 1998), and offer the most robust data for applying advanced panel based econometric techniques aimed at assessing the nature of long run dynamics, analysing specifically the role of time related exogenous shocks of policy or other nature (energy markets).

The relevance of carbon is also depending on the fact that if on the one hand *(absolute) decoupling* – that is a negative elasticity in the relationship emissions-economic development - has been experienced and verified in the literature for local and regional air and water emissions, on the other hand, *(absolute) 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*: a positive but lower than unity emissions-economic development's elasticity.

It is worth noting that even absolute decoupling does not assure sustainability achievements, but only progress towards it, since sustainability depends on capital stock based considerations. However, decoupling assessment is a useful complementary tool for reasoning on sustainability and development (Neumayer, 2003) and may offer more room for policy based thinking.

The EKC literature has moved from basic conceptual intuitions and stylised/empirical facts, which traditionally fed EKC analysis, to the search for theoretical foundations. An extensive overview of the main theoretical issues (firstly developed by Andreoni and Levison, 2001)[2] can be found in Copeland and Taylor (2004) and Brock and Taylor (2004).

Empirical evidence in favour of CKC has been both rare and patchy. Recent works have highlighted that there is some evidence supporting EKC shapes for CO_2, but variable 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 heterogeneous across studies there is some EKC evidence for CO_2 emerging for the OECD countries. This is counterbalancing other rather pessimistic views which also question the foundations of EKC (Harbaugh *et al.*, 2002; Millimet, List and Stengos, 2003).

A relevant note for the current paper is that the existence of an EKC curve in cross country international frameworks, such as OECD based analyses, may depend on the balance between high income countries showing an inverted U shape dynamics and low income countries that present a still positive elasticity. Using standard panel data approaches may produce a false curvilinear relation: slope-homogeneous estimators may suffer of the so called *heterogeneity bias* whereas standard parametric formulations impose polynomial shapes which could be not coherent with the data. 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[3].

This paper aims to contribute to the development of EKC research in three main directions.

First, we compare parametric estimators that explicitly take into account *cross section correlation* as well as *heterogeneous* estimators which allow individual slopes to be derived from sampling or Bayesian approaches, with *non parametric analyses* (Vollebergh *et al.*, 2009) that disentangle income and (common)

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[2] Then other works followed in providing technology based explanations for the EKC path (among others Jaeger and van Kolpin, 2008; Pasche, 2002; Smulders and Bretscgher, 2000; Kelly, 2003; Chimeli and Braden, 2005, 2009).

[3] New studies have regarded analyses of single country panel dataset where within country heterogeneity (region-based) is exploited (List and Gallet, 1999, Carson *and* McCubbin 1997), the inclusion trade factors (Frankel and Rose, 2005; Cole at al., 2006;), energy factors (Aldy, 2006), spatial econometric techniques (Maddison, 2005), semi or full non-parametric setting, including Bayesian approaches (Azomahou et al., 2006; Musolesi *et al.*, 2009; Bertinelli and Strobl, 2005).

time related effects, that are aimed at shedding light on structural differences depending on how different (group) of countries have reacted to exogenous time related factors (policy, energy, technological shocks). The non separability of time and income effects is also tested.

Secondly, in order to investigate the role of potentially path breaking events included in the time related factor, we enrich the literature by testing the relevance of global environmental policy facts (the Rio convention and following Kyoto setting) and energy related events, which may have influenced, for some world areas more than others, the carbon-income relationship at some point in time (as the oil shocks). This is food for though of general and contingent value, given the present recession shock, preceded and maybe followed by high oil prices and the increasing number of environmental policies or coordinated actions applied at regional and possibly world level after the 2009 Copenhagen meeting in December. A contribution we aim to provide is the evidence on the extent to which time - not income - related factors may have shaped EKC in the past: exogenous structural breaks, policy events. As Vollebergh *et al.* (2009, pp.13-14) conclude: *"to what extent more growth also involves fewer emissions crucially depends on emission specific, time related effects which are likely induced by regulatory interventions or other drivers of induced technological change, such as higher energy prices" […] "the different patterns of SO_2 and CO_2 emissions nicely reflect well documented differences in regulatory interventions and induced technological changes between the two policy arenas. The fact that we find and inverted U pattern for SO_2 in relation with time and not income suggests the fallacy of the adage".* Such evidence stimulates thoughts on the need of relying not just on endogenous income effects, following the business as usual (BAU) EKC, but reasoning on how breaking the BAU by policy, or responding and taking advantage of non policy shocks, such as energy crisis.

Finally, an originality of this paper is that it explicitly narrows down the focus to economic, institutional and policy sound country 'groups'/ regions of the world, instead than on OECD or other typically used data. We focus on advanced regions of the world (for now the 'Umbrella group'[4], Northern and southern EU).

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[4] The Umbrella group (has) supported the radical interpretation of the EKC: economic growth that drives technological improvements is what is needed to achieve a sustainable path.

It is worth noting that Kuznets himself rejected the notion of uniform development patterns across time and national contexts. The scholars devoted to building quantitative measures of the economy also believed in the importance of historically-built technological, institutional conditions. Kuznets also advocated that we needed a clear perception of past trends and of conditions under which development occurred: different contexts create different dynamic patterns. Not all forms of economic and institutional progress produce the same level of externalities.

Though policy implications have been sometime linked to the analysis of EKC paths (Cole and Neumayer, 2005), we believe that the literature has so far provided weak policy oriented evidence. Our policy oriented reasoning is then structured on (i) a comparative assessment of EKC shapes for three group of countries, instead of analysing larger samples as often it happens (mainly OECD or even world wide datasets), (ii) an analysis on how taking into account time related factors affects the CO_2-income relation and iii) an in depth econometric investigation on the relevance of exogenous political events, such as the 1992 Convention on climate change, the Kyoto protocol, searching also for other sources of structural breaks. As recognised, (policy) events, including price shocks such as oil shocks and also carbon taxation (Pizer, 2002) may be needed to reshape the business as usual EKC, by smoothing the bell and/or decreasing the income TP (Turning Point) level.

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 decades ago 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[5] (Porter and van der Linde, 1995) and to the intrinsic advantage of reasoning in terms of CO_2 reductions decided in 1997 at Kyoto, which define a compliance with respect to 1990 levels. What happened between 1992 and 1997, and before 1992, matter(ed).

[5] It is well recognised that part of the opposition to the anti Kyoto US position made finally explicit at the convention in Johannesburg in 2002 came from environmental technologies sectors excluded from international 'green markets' (partly linked to the development of clean development mechanisms) by the US position.

Moreover, a lower carbon income elasticity and/or EKC evidence for a group (as Northern EU) could explain stronger support for Kyoto, deriving from better historical environmental performance and favourable structural conditions. The objective of intensifying green and economic competitive advantages spurred by innovation investments (Jaffe *et al.*, 1995; Mazzanti e Zoboli, 2009), that may be to some extent sunk, can be constant source of development. Such reasoning could explain why some countries keep behaving more environmentally than others though in presence of higher and rising abatement marginal costs[6]. How they reacted to some time related shocks integrating policy and innovation externalities dynamics (Gerlagh *et al.*, 2009) may be a major part of the tale.

In a political agenda that is drastically changing as all we know in the climate change arena, 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; Convery, 2009).

The paper is structured as follows. Section 2 presents the data and samples; section 3 focuses on some specification issues and explains the econometric methodology. Section 4 comments on the main results of the analysis and Section 5 concludes with a summary of results and some policy implications.

2. Data and samples

We argued that compared to studies based on OECD country or world wide datasets, which are still the majority in the literature, often depending on the need of exploiting extensive amount of data, a focus on specific regions, and groups of homogenous countries, would instead provide a sounder basis for economic and policy reasoning. Some scholars suggest even higher robustness of time series approaches compared to wide panel polled datasets (Wagner, 2008). Most recent works still focus on world wide datasets (Azomahou *et al.*, 2006), which are often based on OECD countries (e.g. Cole,

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[6] While we write, estimates seem to suggest that (advanced) countries, in order to reach a 20% cut by 2020 (the current EU proposal, with the EU increasing to a 30% cut if all countries should agree on a 20%), should 'collect' from national budgets 100$ billions over ten years, not very huge but still a shock if implemented to fund energy efficiency and renewable energy actions. Some funds would be collected by auctioning carbon quotas, a market existent in the EU since 2005 and possibly emerging in the US and elsewhere. The EU alone estimates to collect 38€ billions each year from auctions by 2020.

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. Taking these countries as a group is not fully relevant in our eyes, if one wants to provide some food for thought in policy terms within the Kyoto and post Kyoto realms. In addition, OECD countries, with regard climate change and other international global public good issues needing cooperation, present variegated political and economic perspectives. OECD is not a relevant group of countries with regard the analysis of international environmental agreements as well. Economic, policy and statistical aspects should be considered jointly. Thus, narrowing down the scope of previous and alike papers (Musolesi et al., 2009) focusing on more countries, dividing between OECD, G8, and developing countries, we decided to focus more in depth on the 'regional areas' that have been leading the climate change policy debate and were associated to Kyoto targets in 1997: (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')[7]. Countries are aggregated on the basis of development-political facts. The umbrella group is a 'political' cluster. Ireland in terms of development is not a northern country. For this paper we opt for an intermediate polling, in between the option of a full time series analysis and the still prevalent choice o considering large groups of non policy relevant countries (OECD, world wide aggregation).

Such groups, sharing some institutional and economic development similarities (Northern and southern EU particularly), that could be behind eventual divergences in emission performances over time, also represent quite well possible homogenous positions at the Copenhagen meeting in December 2009, with the US changing the policy perspective on climate (though the US are still behind the (northern) EU in terms of proposed cuts to emissions) of advanced countries which aim to give priority to

[7] 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%.

national economic objectives over global public good provision[8]. Future extensions may include the group of countries that in Copenhagen, lead by China and India, including Africa which recently expressed a common position, represent the 'reasons' of emerging countries. Many other groups could be selected (coal intensive, on the basis of energy use...). Given most countries ratified Kyoto, this cannot be a clustering criterion.

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 Centre (CDIAC). For our study, we use the subset of emissions data that matches the available time series on GDP per capita[9] on the basis of joint availability, series continuity, and country definitions.

[Table 1 here]

3. Model specification and estimation procedures

Following the recent EKC related literatures, (primary references are Azomahou *et al.*, 2006; Vollebergh *et al.*, 2009), let us suppose that the researcher observes panel data (y_{it}, x_{it}), where y is the logarithm of CO_2 emissions per capita, x is the logarithm of per capita GDP; $i \in \mathfrak{I}$, and $\mathfrak{I}$ is the set of cross-section units $\mathfrak{I}=\{1,2,...,N\}$ and $t \in \wp=\{1,2,...,T\}$ represents the time series observations. A general and, at the same time, an identifiable EKC specification is given by assuming that the income effect, the time effect (eventually heterogeneous across countries) and the idiosyncratic effect are separable:

(1) $$y_{it} = f\left(x_{it}, i\right) + \lambda(i,t) + \varepsilon_{it}$$

where the function $f\colon \aleph \times \mathfrak{I} \rightarrow \mathbb{R}$ captures the effect of income and of individual time invariant heterogeneity on CO_2 emissions ($\aleph$ denotes the set of possible values of x_{it}), the effect of time is

[8] Even if actually carbon abatement implies a mixed public good: carbon emission cuts are correlated to regional and local emissions cuts as well.

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

measured through λ: $\mathfrak{I}\times\wp\rightarrow\mathbb{R}$ and ε_{it} is the remainder idiosyncratic error term. Many researchers (Azomahou *et al.*, 2006) have estimated eq. (1) by assuming $\lambda(i,t)=0$. There are some reasons for such specification. Firstly, it allows for a greater comparability with existing studies. Second, this kind of econometric specification is useful if the researcher is interested in capturing the *global effects* of GDP on CO_2 including the indirect effects linked to the omitted (or unobserved) variables, such as energy prices, technological change, environmental policies, etc, which are correlated with both GDP and time. However, if the goal is measuring the *ceteris paribus* impact of GDP on CO_2 emissions, such specification might be not appropriate. In addition, separating out income and time effects may be useful to shed light on the (policy) structural differences between different groups.

In the following, we provide alternative specifications for both $f\left(x_{it},i\right)$ and $\lambda(i,t)$ in order to give useful complementary statistical information. It is worth noting that given it does not exits a 'general' econometric model that may simultaneously tackle all relevant issues and from which deriving various specifications, we opt for addressing issues that are in our eyes are most compelling for our analysis, such as cross section correlation (§3.1), individual heterogeneity (§3.2) and non constrained functional form (§3.3), thus we are aiming at reconstructing a puzzle by using some of its most relevant pieces for us.

3.1 Unobserved heterogeneity, common slopes and cross-section correlation

First, let us suppose that $\lambda(i,t)=0$ (such restriction imply focusing on the global effect of GDP on CO_2) and that

$$f\left(x_{it},i\right)=\sum_{i'}\alpha_{i'}\mathbf{1}\left(i=i'\right)+g\left(x_{it};\beta\right) \quad (2)$$

where $\mathbf{1}(i=i')$ represents an indicator function corresponding to the cross sectional units i' and it is defined as $\mathbf{1}(i=i')=\begin{cases}1, \text{ if i=i'} \\ 0, \text{ otherwise}\end{cases}$. The term $\sum_{i'}\alpha_{i'}\mathbf{1}(i=i')$ measures the individual fixed effects capturing country-specific unobserved heterogeneity which is not time varying. Adopting the standard parametric approach, we begin by specifying the function $g(x_{it};\beta)$ as a third order polynomial $g(x_{it};\beta)=\beta_0+\beta_1 x_{it}+\beta_2 x_{it}^2+\beta_3 x_{it}^3$ characterised by common slopes across countries[10]. The standard assumption concerning the idiosyncratic part of the models considers that the error term ε_{it} is an *iid* random variable. In many cases, this assumption is clearly unrealistic. 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 could be also the consequence of unobserved heterogeneity dues principally to *"omitted observed common factors, spatial spill over effects, unobserved common factors, or general residual interdependence"* (Breitung and Pesaran, 2008). Standard techniques that do not take account of this dependence would yield incorrect inference. Several tests of cross section independence[11] have been implemented and in all cases they strongly reject the null hypothesis that the errors are independent across countries. In order to correct for the presence of cross-sectional dependence, we employ the following two estimators. 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; and the GLS *slopes constrained* Seemingly Unrelated Regressions estimator (SUR, Zellner, 1962). All these estimators allow individual intercepts but common slopes. Although the common slopes assumption can be restrictive, there are some features – as the simplicity, parsimony and forecast performances- that render homogeneous estimators quite attractive (Baltagi *et al.*, 2000, 2002).

[10] The final model is obtained by dropping the non significant terms.

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

3.2 Heterogeneous slopes and adjustment dynamics

Along with the increasing time dimension of panel data sets, some authors suggested the use of heterogeneous estimators allowing for individual slopes (Pesaran and Smith, 1995; Hsiao *et al.* 1999). This is mainly motivated by 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. A more flexible specification is:

(3) $$f\left(x_{it}, i\right) = \sum_{i'} \alpha_{i'} \mathbf{1}\left(i = i'\right) + g\left(x_{it}; \beta_i\right)$$

with

(4) $$g\left(x_{it}; \beta_i\right) = \beta_0 + \beta_{1i} x_{it} + \beta_{2i} x_{it}^2 + \beta_{3i} x_{it}^3 .$$

Next, we also apply the hierarchical Bayes approach proposed by Hsiao et al. (1999), which might be preferable to other estimators (Hsiao et al., 1999; Baltagi et al., 2004). This estimator makes use of Markov Chain Monte Carlo methods via Gibbs sampling.

Another issue worth to analysing is that of adjustment dynamics. Dynamics effects are crucial in studying EKC with the aim of providing insights on the structural long term differences that may explain the current situation diverse group's face in terms of emission efficiency and future possibilities of abatement. This the reason why we decided to use as many years as possible, at the cost of losing the chance to use additional covariates that are not available over such a long term period. In dynamic models, the parameters of interests are the long run effects and the speed of adjustment to the long run equilibrium. Let consider a heterogeneous dynamic model of the form:

(5) $g\left(x_{it}, y_{it-1}; \beta_i, \rho_i\right) = \beta_0 + \rho_i y_{it-1} + \beta_{1i} x_{it} + \beta_{2i} x_{it}^2 + \beta_{3i} x_{it}^3$.

Within the literature focusing on estimation of dynamic panel models, where the number of time series observations is relatively large, one approach consists at estimating separate Auto-Regressive Distributed Lags (ARDL) equations for each group and examine the mean of the estimated coefficients, the so-called Mean Group (MG) estimator, that it has proved to be consistent (Pesaran and Smith, 1995). The MG estimator, however, does not take into account the fact that certain parameters may be the same across groups. Pesaran et al. (1999) therefore proposed an intermediate estimator, the 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.

3.3 Non constrained functional form and common time effect

The main limitation of the above mentioned approaches is that they impose a polynomial function like (4). In order to remove the polynomial function assumption, the function $f\left(x_{it}, i\right) = \sum_{i'} \alpha_{i'} \mathbf{1}\left(i = i'\right) + g\left(x_{it}; \beta\right)$ can be estimated adopting a semi parametric approach[12]. In particular, the Generalized Additive Models (Hastie and Tibshirani, 1990; Wood, 2006) can be usefully applied. Next, we allow the time effect $\lambda(i,t)$ to enter the relation. Standard parametric formulations introduce temporal fixed effects as:

(6) $\lambda(i,t) = \sum_{t'} \phi_{t'} \mathbf{1}\left(t = t'\right)$

[12] To our knowledge, however, to date it is not possible combining non constrained functional form and heterogeneous (individual) behaviours (the function g has to be assumed to be the same for all countries).

where $\mathbf{1}(t=t')$ represents an indicator function corresponding to the time period t' and defined as $\mathbf{1}(t=t')=\begin{cases}1, \text{ if t=t'}\\0, \text{ otherwise}\end{cases}$.

Otherwise, a common trend can be introduced:

(7a) $\lambda(i,t)=\phi t$,

(7b) $\lambda(i,t)=\phi_1 t+\phi_2 t^2$,

(7c) $\lambda(i,t)=\phi_1 t+\phi_2 t^2+\phi_3 t^3$,

More flexibility can be obtained by allowing an individual time trend $\lambda(i,t)=\phi_i t$ as in Heckman and Hotz's (1989) random growth model. As underlined by Vollebergh *et al.* (2009), introducing an higher order individual trend as $\lambda(i,t)=\phi_{1i} t+\phi_{2i} t^2+\phi_{3i} t^3$ will capture all the time variation rendering $f(x_{it},i)$ essentially unidentifiable. They thus suggest that the *most reasonable* decomposition is not allowing the function $\lambda(i,t)$ to be country specific. Rather, they suppose that the function $\lambda(i,t)$ is the same within homogeneous groups of countries but differs between groups.

This shows links to our research idea but, while they categorise countries according to their energy use, our aggregation is based on the expressed *environmental policy orientation* towards the amount of abatement needed for tackling climate change and the means (national abatement versus abatement in other countries). This orientation is somewhat linked to 'development' stages (northern EU versus southern EU). Nevertheless, we aim at studying the relationship between different policy perspectives and the structural long term dynamics, then including an analysis on how time effects and exogenous (policy) events may have affected (differently) those selected groups of countries. Consequently for each group of countries ('Umbrella group', 'EU North' and 'EU South') the following *semi parametric* model is estimated:

(8) $y_{it}=\sum_{i'}\alpha_{i'}\mathbf{1}(i=i')+s(x_{it})+f(t)+\varepsilon_{it}$

where *s* and *f* are smooth functions of x and t, respectively. Thin Plate Regression Spines (TPRS) have been used as a basis to represent the smooth terms, since they have some appealing statistical properties (Wood, 2006) and the smoothing parameters have been chosen using the Generalised Cross Validation (GCV) criteria[13].

Finally, a more *general* and - at the same time - *identifiable* specification is provided by assuming that the time 'group effect' (e.g. North EU) and income effects on carbon emissions are not separable:

$$(9) \qquad y_{it} = \sum_{i'} \alpha_{i'} \mathbf{1}(i = i') + s(x_{it}, t) + \varepsilon_{it}$$

It is worth noting that equation (9) is still interpretable using a 3 dimensions surface plot and that model (8) will be tested against model (9) using an approximate F test (Wood, 2006).

4. Empirical evidence

We present evidence first (§4.1) by 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. Unobserved heterogeneity, and cross-section correlation is addressed by correcting non parametrically the covariance matrix in a fixed individual effects framework (DK) and by (slope constrained) SUR models; then, heterogeneous slopes and adjustment dynamics are investigated by Hierarchical Bayes, PMG and MG models. Results from other ancillary specifications are available upon request[14]. Then, non constrained functional forms and common time effects, such as GAM with

[13] Since the GCV is known to have some tendency to over fitting, it has been suggested to increase the amount of smooth by correcting the GCV score by a factor $\gamma \approx 1.4$ which can correct the over fitting without compromising model fit (Kim and Gu, 2004).

[14] Results obtained using alternative homogeneous panel data estimators not allowing for cross-section correlation such as the Least Square Dummy (LSD) estimator (FEM) allowing for individual fixed effects and the Dynamic ordinary least squares (DOLS) estimator for the cointegrated panel data regressions (Kao and Chiang, 2000; Saikkonen, 1991) are available upon request. As far as heterogeneous estimators Upon requests are available results for both 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 and 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

individual fixed effects and GAM with individual fixed effects and common time effect (that directly links to Vollebergh *et al.,* 2009) are introduced.

Secondly (§4.2), in order to add an explicit policy flavour and give content to 'time effects', we test through structural break analysis whether exogenous *policy events* such as the 1992 Climate convention, that gave birth to Kyoto, and the 1997 Kyoto convention itself have affected the 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 dynamics: slope heterogeneity, flexible relations, time related effects

Figures 1–3 depict the relationship between CO_2 and income for the three samples. We provide real data, and the curve fitted 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.

[fig.1-3 here]

When taking account of cross sectional correlation (DK, SUR[15], table 2) in a slopes homogeneous' framework, we note that quadratic specifications are significant for all the analysed cases, while the cubic specifications are not.[16] Nevertheless, the evidence is different across groups: while the TP for EU NORTH is within the range of observed values ($13,000/14,000) this is not the case for the

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. Results are very similar, showing an unexpected robustness across (similar) models.

15 Dynamic SUR estimates do not change the SUR evidence and are available upon request.

16 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.

UMBRELLA group and EU SOUTH, which show similar (slightly higher for EU south) TPs , around \$45,000-65,000 per capita[17]. TP for EU NORTH may seem quite low, but they associate to countries at the top ranking in terms of GDP, public good provision, human development index; we also note that comparisons are hard since the literature rarely presented, if any, TP for EU north and south specifically. Results could be consistent with the 'early move' on environmental issues, even regarding energy/global facts such as CO_2, where myopic and free riding behaviour by single countries is more likely to occur. The US, for example, early moved towards NOx and SOx by adopting the various clean air acts since the 70's (Lee and List, 2004), but lagged on carbon.

As far as slope heterogeneity (Hierarchical Bayes, MG, PMG, table 3) is concerned, we test the null hypothesis of coefficients constancy across countries in a static model. Secondly, the slope homogeneity is tested in a dynamic framework by using the Hausman type test comparing the MG and the PMG estimates. Both tests clearly reject the null hypothesis of long-run homogeneity.

PMG results resemble those of homogeneous estimators – it may be included within them to some extent. On the contrary, the novelty provided by the MG (the non reported Empirical Bayes, Iterative Empirical Bayes and Swamy estimators provide similar results) is that for UMBRELLA and EU SOUTH a quadratic shape obtained under slope homogeneity vanishes. The quadratic relation with within range TP is confirmed instead for EU NORTH.

Hierarchical Bayes estimates provide slightly different results. They provide EKC quadratic shapes in all cases, but for anti-Kyoto countries (UMBRELLA and EU SOUTH), the quadratic terms are very low (but precisely estimated) and the estimated TPs are well above the range of observed values. Instead, the TP for EU NORTH is fairly consistent with those obtained with the other heterogeneous estimators, showing again coherency across models as far as EU north countries are concerned.

To sum up, the set of heterogeneous based estimators provide robust evidence of an EKC for the EU north countries and only relative delinking for the other two groups. The somewhat different evidence we observe is worth noting from a methodological point of view. If on the one hand, all

[17] 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 non reported homogeneous estimators.

homogenous panel estimators tend to erroneously indicate a quadratic path which may be the result of the heterogeneity bias, on the other hand heterogeneous estimators tend to provide a linear relation when the true relation is monotonic but eventually nonlinear (figures 4-5). The analysis of TP nevertheless shows some coherence in the end between the two sets.

[fig.4-5 here]

More flexibility in the relationship can be allowed by using the semi parametric (GAM) models commented on above (§3.3)[18]. First, model (8) with $\lambda(i,t)=0$ presents results that are quite similar to those commented on above for parametric panel models: only EU NORTH shows a sound EKC shape but it clearly indicated that UMBRELLA and EU SOUTH presents monotonic nonlinear (but clearly non quadratic) shapes (fig. 6)[19]. Using an F type test, both the linear and the quadratic model - which results from the above presented parametric estimates- are tested against the non linear (non parametric) specification. In all cases the nonparametric model is clearly the preferred one.

Second, and very relevant, when removing the assumption $\lambda(i,t)=0$, the outcomes with group's specific non parametric temporal trend instead present a very different picture (fig.7). While on the one hand the relation turns into a bell shaped curve (or at least, looking at the confidence interval, there is a clear threshold) for UMBRELLA and EU SOUTH, this is now monotonic and *positive* for EU NORTH. Nevertheless, the relation between emissions and the time factor is positive for UMBRELLA and EU SOUTH and significantly negative for EU NORTH[20]. Though different, such evidence is also coherent with the previous set of outcomes, adding more insights. Southern EU countries actually show some signal of delinking related to income, not time. This could be linked to energy intensity of GDP increasing in some countries. Italy, though not complying with its Kyoto targets, is a country that given idiosyncrasies in the energy market (historically high energy prices and high monopoly powers)

[18] We present graphical outcomes. Estimates are available upon request. For the non parametric GDP factor the estimated degrees of freedom are included in graphs, the significance level of the smooth functions is always very high.
[19] Approximate F test strongly rejects the linearity assumption.
[20] A similar outcome derives from a parametric model with individual and common linear trend (results available), wherein northern EU show san EKC shape with TP outside range while an ECK with TP within range is presented by the other two groups. Nevertheless, the time covariate coefficient is negative and significant for northern EU and positive for the other two. It confirms the relevance of the time factor in explaining the shape of EKC.

may lead this group of countries Austria that possess nuclear as well, is another case. In depth insights on higher country specificity are nevertheless cope for further research.

[fig.6-7 here]

Model (8), though providing sound insights is nevertheless not the preferred specification, in the end, if tested against (9) by an approximate F test[21].

Fig.8 plots in three dimensions what the assumption of non separability regarding income and time effects generates. The 3D framework sketches (diverse angles are available upon request) provide some additional insights. For both UMBRELLA and EU SOUTH, the first part of the time dynamics, say roughly 1960-1973, present carbon income monotonic shapes. In the middle of the 'time evolution', say 1974-1987, U shapes for umbrella and non linear N–like shape for southern EU seem to emerge. We recall that within this kind of 'cross section' discussion of results (*sectioning* by time), non linear trends are then representing within country heterogeneity in GDP and emission per capita, that emerges at graphical level. The final part of the observed period, say 1988-2001, does not show remarkable changes, confirm that income effects, if any, are of a positive nature: N shapes prevail. Though some of those countries may have behaved better than in the past, it remains that Australia, US, Norway and Japan are all well out of reach of Kyoto targets, as well as Spain (quite heavily, though together with other of those countries carbon emissions were permitted under Kyoto), Portugal, Ireland and Italy (Italy alone had to cut emissions). Even Austria performed quite badly, increasing instead of reducing as agreed its carbon emissions. This shows that carbon issues as they bring together national and global issues in a mixed public good are quite peculiar (Cornes and Sandler, 1984; Loeschel and Rubbelke, 2009), as Austria is often found to be homogenous to Germany with regard environmental policy commitment (waste).

[21] This evidence may relate to some endogeneity involving time related effects, such as technology and (national) environmental policies.

As far as the climate change leaders (EU NORTH), we note that in the first phase the shape is non linear (N-like), turning to a U shape in the second part, then concluding with a (globally negative) non linear shape, that nevertheless may hide some heterogeneity. Egli and Steger (2007) provide an interesting policy based motivation for N (or M as they define) shapes: if the economy develops along the increasing path, a policy breaking stimulus may reduce the level of emissions, but after that pollution again follows a (lower) increasing path before reaching a TP. This dynamics could represent a possible policy oriented explanation of the non linearity we here markedly observe, the other being usual country heterogeneity when we pool even quite homogeneous countries such as in this work.

Though all countries witnessed years of emission reduction and most are within or very close to Kyoto targets, this non linearity is explicable. Among countries associated with very high GDP, Sweden and Denmark, the latter has recently counter intuitively shown difficulties in carbon reduction, and will not comply with Kyoto. Despite the relevance of renewables such as wind energy, some EU countries, Denmark may be an example, as well as Italy, still rely quite heavily on coal fuelled energy. A negative response for the environment to oil shocks can be, and it was often, a strengthening of the use of coal, a fact that Denmark experienced in the 80's for example (decomposition analyses are a tool to investigate such micro issue, Jacobsen, 2000 is an example on Denmark over 1966-2002). Concerning other countries, the relatively worse performances of France and The Netherlands with regard to Germany, Finland and the UK can explain the other part of non linearity, when observing such countries, all around similar GDP per capita, in a given time period. Overall, signals of path breaking events occurring in the 80's and beyond arise from the globally negative trend fig.8 shows.

We believe that the issue is not what penalizes northern EU with regard to income related dynamics, but what has advantaged northern EU regarding the time related effect. Summing up, we find that T is a better explanatory factor for EU north (after 1980, linking to §4.2); we could show that for countries such as Sweden and Denmark over 1960-2001, the trend of Y slows compared to T after 1980 T, then start regrouping in the mid of the decade, while emissions stabilize soon after 1980. The correlation between T and carbon is intuitively negative and more statistically significant than for income. On the contrary, for the US and Spain the GDP trend has been quite different from the T for many years and emissions have not stabilized for (internal) energy reasons (the US, Australia among others).

In our eyes, a still existent process of de industrialization in one case, and a string pattern of green technological investments in others, intertwined with higher than average stringency of environmental policies, were the major preconditions of a favorable 'climate' for greenhouse gas reductions. The UK may have exploited a comparative advantage in the strong shifting from industry to services and finances that began around the 1990 and even before. Scandinavia countries were the only to implement quite full ecological tax reform in the early 90's partly as a consequence of the 1992 Delors white book. High incomes potentially lead to high investments in environmental technologies, patents among others (Johnstone and Hascic, 2009).

The following section explores what may lie at the heart the time related effect we highlighted above.

[fig. 8 here]

[Table 2 -3 here]

4.2 Evaluating 'events' in the CKC dynamics: a time series approach

This section aims at assessing the impact of a *(postulated) event* on the carbon-income relationship. The 'intervention analysis' developed by Box and Tiao (1975) is the (*time series*) methodology of reference. Closely related to this work are papers focusing on the assessment of environmental policies on pollution (Sharma and Khare 1999; Lee and List, 2004)[22]. The intervention analysis decomposes a time series as a sum of a stochastic process – as an ARIMA – plus the intervention components –as public policies – which could modify the *normal* evolution of the time series.

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[22] Other relevant contributions include Fomby and Hayes (1990) who examine the impact of redistributive policies in the US; 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.

More particularly, this section is intended to set links to the previous analysis, by providing some specific insights. In fact, the decision of separating out income and time effects still leaves unexplored the content of this time effect, as also Vollebergh *et al.* (2009) note in their conclusions.

In order to accomplish this task, we set time series for each group of countries (as the countries' average). The cost of adopting such framework is the loss of individual heterogeneity within each group of countries. Second, the standard intervention analysis is *slightly modified* and adapted to the context of a CKC. This is done by replacing the ARIMA specification for the stochastic part of the model – as usual in intervention analysis - with a polynomial function of per capita income which accounts for the CKC dynamics. This can be written as:

$$(10) \qquad y_t = f\left(\mathbf{x}_t, \boldsymbol{\theta}\right) + g\left(\boldsymbol{\delta}, \boldsymbol{\omega}, \boldsymbol{\psi}, t\right)$$

where y_t denotes per capita CO_2 emission, $f\left(\mathbf{x}_t, \boldsymbol{\theta}\right) = \theta_0 + \theta_1 x_t + \theta_2 x_t^2 + \varepsilon_{it}$ corresponds to the CKC relation previously estimated, where x_t is per capita GDP. Finally, $g\left(\boldsymbol{\delta}, \boldsymbol{\omega}, \boldsymbol{\psi}, t\right)$ 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 $\boldsymbol{\omega}$.

As far as specific events that we consider, the interventions capturing the occurrence of the 1992 UN Framework Convention[23] (and the consequential 1997 Kyoto protocol) has been introduced. They can be supposed to have a *'gradual start, permanent duration'* effect on the relation. This can be modelled combining a step function with an exponential (or first order) transfer function allowing for a (eventually) *non linear* effect of the intervention:

[23] This postulated break is coherent with the hypothesis that some countries may have acted as early movers with regard to the Kyoto arena post 1997, on the basis of either/both the 1992 convention or/and even by before 1992 events.

(11)
$$\psi_t = Step\_1993_t = \begin{cases} 1, \text{ if } t \geq 1993 \\ 0, \text{ otherwise} \end{cases},$$
$$g(\boldsymbol{\delta}, \boldsymbol{\omega}, \boldsymbol{\psi}, t) = \frac{\omega}{1-\delta \mathrm{B}}\psi_t$$

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 the event is given by ω , and δ 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. Depending on the value of δ , the intervention will produce a *permanent* or *transitory* effect. Alternatively, a *linear and permanent* effect can be modelled directly using a 'ramp' function:

(12)
$$\psi_t = Ramp\_1993_t = \begin{cases} t-1992, \text{ if } t \geq 1993 \\ 0, \text{ otherwise} \end{cases},$$
$$g(\lambda, \boldsymbol{\psi}, t) = \lambda \psi_t$$

where λ measures the magnitude of the change in the trend of the series[24].

The parameters' estimates for three main groups (Umbrella, EU NORTH; EU_SOUTH) are in table 4 and real and fitted values are plotted in fig. 9-11. Overall, the model based on the ramp function is preferred.

As far as EU north countries are concerned, relevant results appear, that are fully compatible and complementary with those obtained in §4.1. In fact only the per capita income is significant and positive, while its square is not. Concerning the interventions, a negative and highly significant coefficient λ emerges in association to the trend change occurred after 1992 (or alternatively, 1997). This evidence may provide contents to the negative time effects we highlighted above.

[24] 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 most preferred. The main quality of the ramp specification (11) is that it allows for more degrees of freedom with respect to the step – first order intervention (12). If the true effect is linear it is the most efficient specification.

The Umbrella[25] and EU-south groups are also again similar with regard to the income-environment relationship: first, EKC shapes present a quadratic path with a turning point outside the range of observed values, secondly, the coefficient λ, representing the trend change, is always significant, but positive. The evidence highlights the fact that 1992 Framework Convention (and 1997 Kyoto) did not have a negative effect on their emissions' level. 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[26].

It is worth noting that, following the application of an *'automatic outliers selection procedure' (as in Charles and Darné, 2006)* other structural breaks have been detected. First, a *permanent-gradual* shift in the early eighty's (1980) has occurred for the EU North group. This is modelled combining a step function with an exponential transfer function similar to eq. (11) and the change occurred after 1980 is measured by the parameters ω_{80} and δ_{80}, indicating respectively the magnitude of the impact and its decay pattern. Estimations indicate a negative nonlinear and highly significant break's path. 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[27], which is characterised by efforts towards higher energy efficiency and increasing environmental innovations (Jaffe et al., 1995). Finally, for the Umbrella Group, a transitory-abrupt change is detected in the mid eighty's (1983-87) and it is modelled as $\pi_t = \begin{cases} 1 \text{ if } 1983 \le \text{t} \le 1987 \\ 0, \text{ otherwise} \end{cases}$, and $g(\tau, \boldsymbol{\pi}, t) = \tau\pi_t$ where τ is the parameter to be estimated.

Overall, then, looking at the picture until 2001, it seems that the absolute delinking experienced by Northern EU countries is not attributable to development related factors which affect positively the level of emissions, but it is more the outcome of path-breaking policy and other exogenous 'energy

[25] A temporary change relative to the period 1983-86 has been detected and introduced in the model.
[26] According to the automatic outliers selection, a significant and abrupt negative break occurred over the period 1983-87 for the Umbrella group.
[27] We note that this 'outlier' analysis reveals a significant break only for EU north. This is coherent with our comments.

events'. These are the *'environmental climate change conventions'*, and the consequential Kyoto protocol, and 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[28]. As analysed by Panopoulou and Pantelidis (2009) oil crisis affect carbon 'club' convergence in per capita carbon emissions. Their study on clubs and structural similarity along time in the dynamics show that while convergence at world level, among all countries, was significant over 1960-85, it is not significant over 1975-2003. Events matter. The fact that they find overall 4 clubs that may be aggregated into 2 macro clubs (advanced and not advanced economies), with EU countries converging in the steady state, is not in contrast but complementary to our analysis which has a different focus. We provide evidence that along the dynamics even quiet similar advanced countries may diverge, that shock events could matter, and that heterogeneity between and within groups is peculiar and worth being analysed. Within group heterogeneity is scope for further research.

Along a temporal dimension, the climate change political emphasis emerging in the 90's – in presence 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 quite limited to Northern EU countries – with some other signals of path breaking events for Umbrella, probably driven by some specific country. They 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) in the 90's larger investments regarding CO_2 reduction, though probably lower marginal costs of abatement.

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 medium level oil prices.

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[28] Though even the second break we find, around early 90's, may also be due to the Iraq war frictions in oil markets (someone could argue that wars mattered more than policies for CO_2 abatement!), we believe that the Rio convention was an event that changed the market and policy behavior of northern EU countries more than others. Oil prices did not rise in the early 90's much as a consequence of the war then.

Though in the short term both deflationary (negative demand based shocks) and inflationary (cost based shocks) 'benefit' the environment in the short term by as scale reduction of the economy, one may wonder whether in the long run cost shocks are more effective in rising environmental efficiency than, for example, current (green) recovery packages acting as a fiscal stimulus shock to the depressed economy.

[Table 4 here]

[Fig. 9-11 here]

5. Conclusions

This study has provided new CKC evidence embedding the analysis in a time related and policy perspective. We focus attention on three groups of countries in the 'political economy arena' related to Kyoto (and post Kyoto) frameworks: the Umbrella group, 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, policy and methodological point of views.

The first part of the analysis focuses on the global effect of income. We find that the Umbrella and EU south groups, which were and still are less in favor of stringent climate policies, have not experienced a TP in the 'carbon Kuznets curve' yet, as expected. At least, there is evidence of relative delinking in the carbon-income relationship, with elasticities estimated around 0.45-0.50. The EU north countries instead show robust EKC shapes. We thus bring up an interesting connection between the EKC and political economy considerations for global climate agreements. Namely, we point out the possibility that that Northern EU nations expressed higher likelihood to ratify the Kyoto Protocol and tougher climate change efforts given their historical 'dip' in emissions rates.

Next, we consider how time related factors entered in the CKC relation. Firstly, by addressing income and time effects in the semi parametric *panel data* models, we find that the absolute delinking associated to EU northern countries is prevalently driven by time related factors rather than pure income dynamics. *Time series* intervention model methodology has been then adapted to the analysis of CKC in order to sheds some lights on the exact nature of time related factors. Exogenous path breaking 'policy events' appear to matter. The income-emission relationship is in fact affected by such events, at least for Northern EU countries. The period from Rio 1992 to Kyoto 1997, 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. Scandinavian countries implemented green fiscal reforms aimed at achieving economic-environmental 'double dividends', Netherlands and Germany introduced some elements of ecological taxation in the system; UK concluded the restructure of the economy towards services away from manufacturing. All such interventions added up to the post second oil shock energy efficiency restructuring already in place since the 80's.

We indeed find some signs that the absolute delinking associated to EU northern countries may also largely depend on exogenous shocks occurred well before the environmental conventions of early 90's, showing some path dependency in CKC. The tale may be that this group of countries took advantage of the oil shock to restructure the economy and consequentially took early actions for setting a 'green' technological competitive advantage. These pre Kyoto facts largely explain their strong commitment towards climate change, as they were better positioned and already on the track in 1997 compared to 1990 targets. 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. As far as the comparison between EU North and EU south countries is concerned, some conceptual motivations that are behind the EKC dynamics may explain why northern countries took an early action: they were in the time after the second oil shock well higher with regard income per capita, and thus more developed and moving towards a larger share for services in their economies, with a reduced role for industry. This story is made of different idiosyncratic pieces of the puzzle: if the UK started a decarbonisation first with a rapid shift from industry to services, then taking a leadership in climate change policies, Germany and Scandinavian countries brought together policy actions with investments in green technological options. Such relative success is not irreversible. As an example, the current 'leader' in climate change political debate and main responsible of the northern EU TP in the CKC, the UK, is experiencing a minor 0.5% cuts per year after having exploited the above mentioned benefits of the economy reshuffling towards services and 'dash for gas' options. The partial failure, in terms of expected carbon cuts, of the UK climate change levy (associated to the CCA related 'agreements') may call for new stricter policies (Martin et al., 2009). France is thinking about a carbon tax on top of the noteworthy EU ETS scheme. Thus, the EU 'advantage' is not to be taken for granted and the arena is open to new changes in future scenarios.

Nevertheless, for a comprehensive policy discussion, 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.

The evidence we provide may be an example of the fallacy of the simplistic EKC argument: even at the same income, different innovation and policy dynamics can lead to quite different emission performances. Economic growth is not the solution to the climate change issue; the factors that may be spurred by income growth, including stricter policies, co evolve together with the restructuring of the economy. Different stories are possible behind comparable trends, given that economic growth simultaneously affects ecological, economic, technological and political contexts. Thus, the way income influences environmental quality cannot be expected to be a space-free and timeless relationship.

Thus, in the end, Northern EU spoke stronger to carbon abatement starting from the early 80's. This is in part a known fact but we provided some insights regarding where the dynamics was broken. It is true that the second oil shock made a great deal, and that nuclear power investments also probably affected the dynamics (France as a major example in the group) at the time, as well as the structural decarbonisation of the UK that began under Thatcher governments. Nevertheless, some EU countries responded differently to southern EU countries and moreover to other G-8 economies. Differently in terms of 'commitment' towards environmental policy and environmental competitive advantages through energy and green technologies. Dechezlepretre et al. (2009) show that the rise in innovation trends (patents) starts in the really 90's and then strongly after 1998, and less for US and Australia than for others annex I counties. Renewable energy technologies also show two peaks: early 80's and early in this century (2003 last data), with a U shape that starts rising again around 1993. Specific and quite radical carbon capture and storage technology show quite a different picture, with a decrease in the early 90's but a rise after 1998. Those are on average all signals that the breaks we find have reasonable policy and technological pillars.

Shocks may – symmetrically – impact, but responds of single countries and groups may differ. Thus time matters for determining CKC, though energy efficiency choices, technology and (early moving strategy) in national and supra national policy actions. How the current crisis – not a cost/supply one – eventually influence the CKC is an open question for the future.

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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.

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

Baltagi B.H., Griffin J.M., 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 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.

- (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

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

Box G.E.P., 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., 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.

Charles, A., O. Darné (2006), Large shocks and the September 11th terrorist attacks on international stock markets, *Economic Modelling*, 23 683-698.

Chimeli A., Braden J. (2009), A capital scarcity theory of the EKC, *Environmental and development economics*, 14, 541-64.

- (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., Neumayer E., (2005), Environmental policy and the environmental Kuznets curve: can developing countries escape the detrimental consequences of economic growth?, In P. Dauvergne (Ed.), *International Handbook of Environmental Politics*, pp.298-318, Cheltenham and Northampton: Edward Elgar.

Convery K. (2009), Origins and development of the EU ETS, *Evironmental & Resource economics*, 43, 3, 391-412.

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

Cornes, R.C., Sandler, T. (1984), Easy riders, joint production, and public goods, *Economic Journal*, Vol. 94 pp.580-98

Dechezlepretre A., Glachant M., Hascic I., Johnstone N., Meniere N. (2009), Invention and transfer of climate change mitigation technologies on a global scale: a study drawing on patent data, FEEM working paper 82, 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., Kraay A. C. (1998), Consistent covariance matrix estimation with spatially dependent panel data, *The Review of Economics and Statistics*, 80, 549–560.

Egli H Steger T. (2007), A Dynamic model of the environmental Kuznets curve: turning point and public policy, *Environmental & resource economics*, 36, 15-34.

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., 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. (2004), *Longitudinal and Panel Data: Analysis and Applications in the Social Sciences*, Cambridge University Press.

- (1995), Assessing cross-sectional correlation in panel data, *Journal of Econometrics,* 69, 393-414.

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

Galeotti M., Manera M., Lanza A. (2009), On the robustness of robustness checks of the EKC hypothesis, *Evironmental & Resource economics*, 43, 3, 369-90.

Gelfand A.E., Smith A.F.M. (1992), Bayesian statistics without tears: a sampling-resampling perspective. *American Statistician* vol.46, pp.84-88.

Gerlagh B., Kverndokk S., Rosendhal K. (2009), The optimal time of climate change policy: interaction between carbon taxes and innovation externalities, *Evironmental & Resource economics*, 43, 4, 551-74.

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.

Hastie, T., R., Tibshirani (1990), Generalized Additive Models, Chapman and Hall.

Heckman, J.J. , V.J. Hotz (1989), Choosing Among Alternative Nonexperimental Methods for Estimating the Impact of Social Programs: The Case of Manpower Training, *Journal of The American Statistical Association*, 84(408), 862-874.

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.

Kim, Y.-J., C. Gu (2004), Smoothing spline Gaussian regression: More scalable computation via efficient approximation, *J. R. Stat. Soc. Ser. B Stat. Methodol*, 66 337-356.

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.

Lee J. List J. (2004), Examining trends of criteria air pollutants: are the effects of governmental intervention transitory?, *Environmental & Resource Economics*, Vol.29, 1, 29-37.

List J.A., Gallet C.A. (1999), Does one size fits all?, *Ecological Economics*, vol.31, pp.409-424.

Lloyd T., Morrissey O., Reed G. (1998), Estimating the Impact of Anti-Dumping and Anti-Cartel Actions Using Intervention Analysis, *Economic Journal*, 108, 458-76, Löschel, A., Rübbelke D. (2009), Impure Public Goods and Technological Interdependencies, *Journal of Economic Studies*, 36 (6)

Jacobsen H.K. (2000), Energy Demand, Structural Change and Trade: A Decomposition Analysis of the Danish Manufacturing Industry, *Economic Systems Research*, Vol. 12, No. 3, pp.319-343.

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, working paper 38.2008, 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.

Mark, N.C., M. Ogaki and D. Sul (2004), Dynamic Seemingly Unrelated Cointegration Regression, *Review of Economic Studies.*

Martin R. de Preux L., Wagner U., (2009), The impacts of the climate change levy on business : evidence from micro data, CEP/LSE, London school of Economics, mimeo.

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. Zoboli R. (2009), Environmental efficiency and labour productivity: trade-off or joint dynamics?, *Ecological Economics*, vol.68, 1182-94.

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.*

Musolesi A., Mazzanti M., Zoboli R. (2009), A Bayesian Approach to the estimation of EKC for CO_2, *Applied Economics*, i-first

Neumayer E. (2003), *Weak versus strong sustainability*, Cheltenham and Northampton: Edward Elgar.

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.

Panopolou E. Pantelidis T. (2009), Club convergence in carbon dioxide emissions, *Environmental and Resource Economics*, vol. 44, pp. 47-70.

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.

Pizer W.. (2002), Combining price and quantity controls to mitigate global climate change, *Journal of public economics*, 85, 409-34.

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.

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, 147-62.

Shafik N. (1994), Economic Development and Environmental Quality: An Econometric Analysis, *Oxford Economic Papers*, vol.46, pp. 757-73.
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.
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., Noordewier T. (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., Melenberg, B. and Dijkgraaf, E. (2009) 'Identifying reduced-form relations with panel data: The case of pollution and income', *Journal of Environmental Economics and Management*, 58: 27-42.
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.
Wagner M. (2006), The Carbon Kuznets Curve: a Cloudy Picture Emitted by Bad Econometrics?, working paper economic series 197, Wien, Institute for Advanced Studies.
Wood, S. (2006), Generalized Additive Models: An Introduction with R, Chapman Hall.
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 allowing for cross sectional dependence: DK, SUR

ESTIMATOR	DK						SUR					
	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	
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
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
EKC shape	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	
Turning point range	out		in		out		out		in		out	

Table 3 – Heterogeneous estimators: PMG, MG and Hierarchical Bayes

Model	PMG						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)	3.041	2.067	12.846	5.375	3.117	4.485	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)	-0.126	-1.640	-0.687	-5.452	-0.152	-4.000	…	…	-0.654	-5.070	…	…	-0.163	-3.630	-0.922	-36.888	-0.088	-2.667
EKC shape	inverted U		inverted U		inverted U		monotonic		inverted U		monotonic		inverted U		inverted U		inverted U	
Turning point ($1995)	174,113.091		11,491.294		28,375.730				11,785.41				62,501.4		13,159.87		236,806.82	
Turning point range	out		in		out				in				out		in		out	

(…) means not included given not significance

Table 4 – Structural analyses on events

Specification	θ_0	θ_1	θ_2	ω	δ	λ	τ	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_SOUTH											
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_NORTH											
Step_1993	-5.34(.00)	.68(.00)	-	-.01(.17)	1.22(.00)			-.10(.00)	.74(.00)	-142.56	-132.28
Ramp_1993	-5.32(.00)	.68(.00)	-			-.02(.00)		-.10(.00)	.72(.00)	-141.69	-133.40
Step_1997	-5.33(.00)	.68(.00)	-	-.05(.02)	.81(.00)			-.09(.00)	.77(.00)	-144.73	-134.46
Ramp_1997	-5.31(.00)	.68(.00)	-			-.04(.00)		-.09(.00)	.77(.00)	-146.07	-137.51

p values in brackets

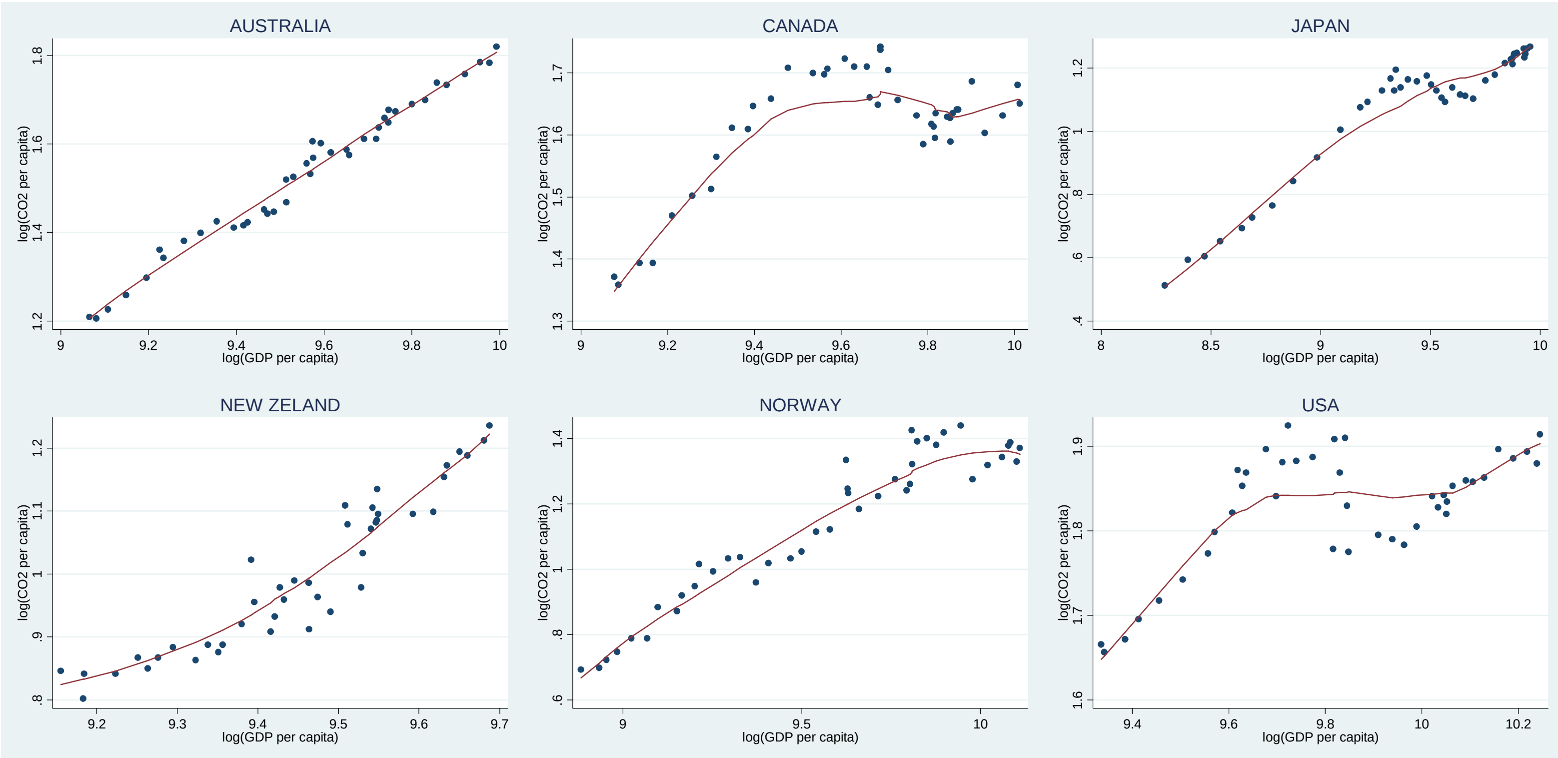


Figure 1. UMBRELLA countries (scatter : real values. Line : robust locally weighted scatterplot smoothing)

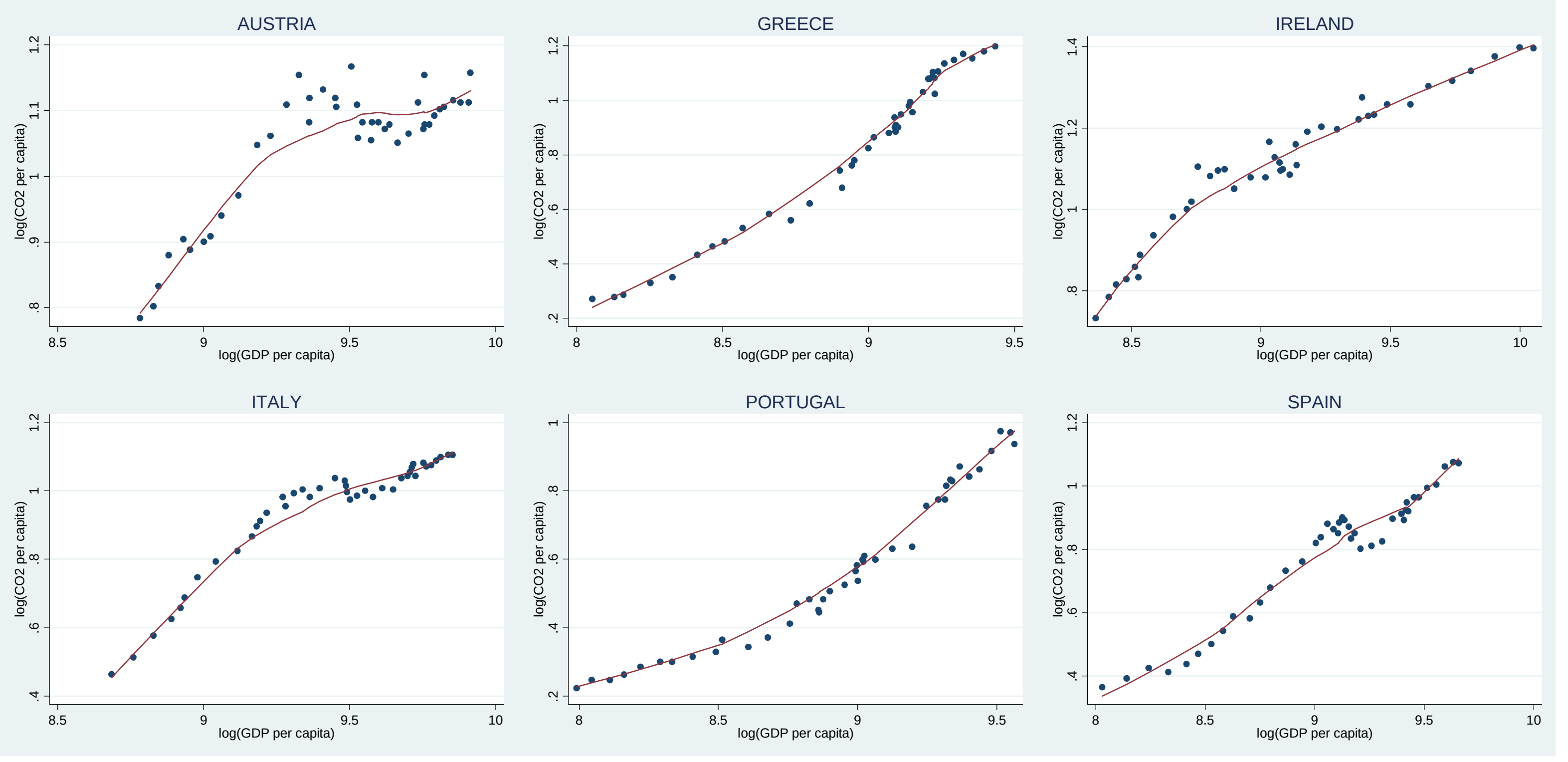


Figure 2. EU-SOUTH countries (scatter : real values. Line : robust locally weighted scatterplot smoothing)

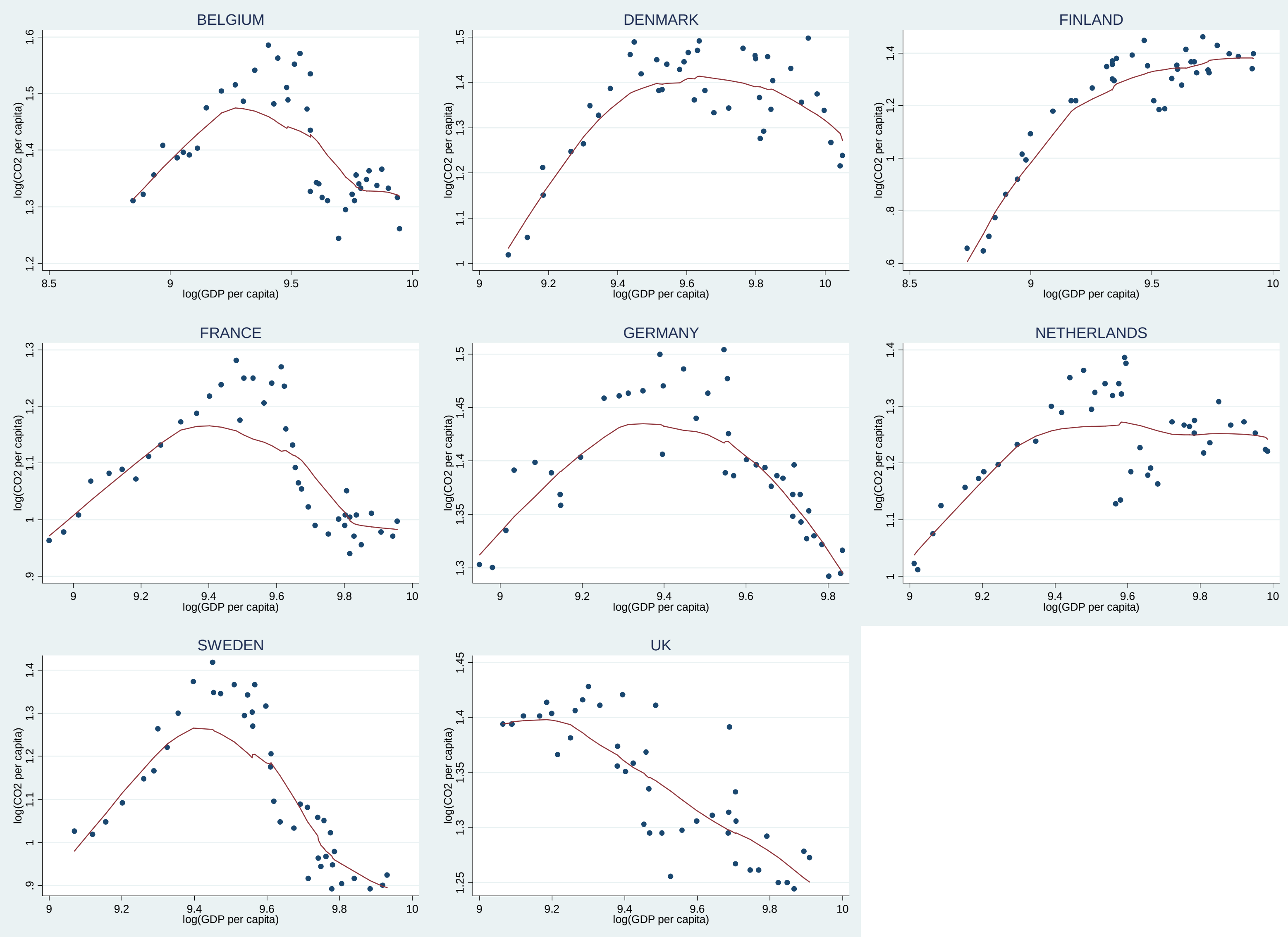


Figure 3. EU-NORTH countries (scatter : real values. Line : robust locally weighted scatterplot smoothing)

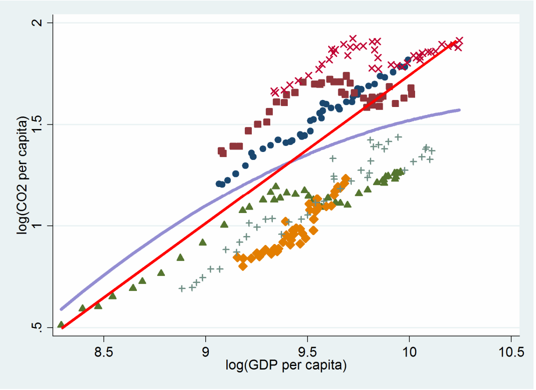


Figure 4. Umbrella countries: real and fitted values with homogeneous (DK) regression and heterogeneous (MG)
(scatter : real values. Straight line : MG. Quadratic line: DK)

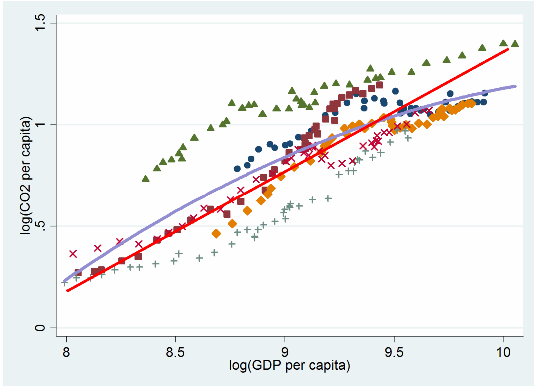
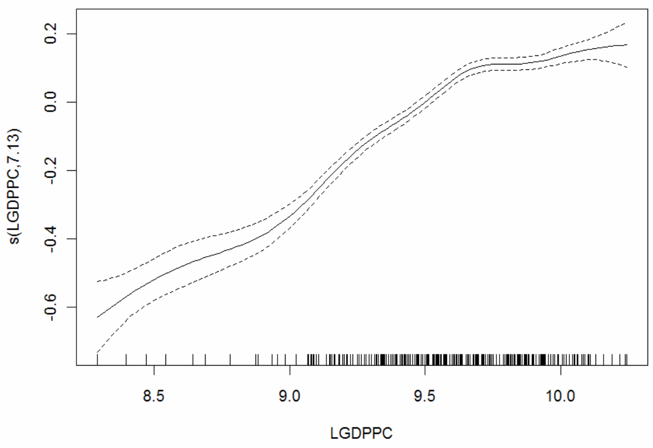
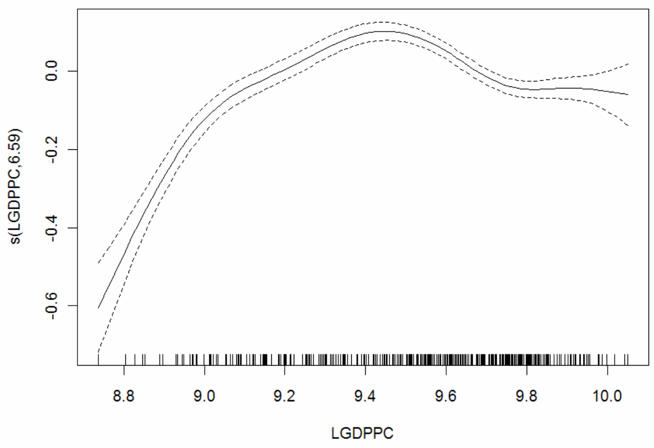


Figure 5. EU-SOUTH countries: real and fitted values with homogeneous (DK) regression and heterogeneous (MG)
(scatter : real values. Straight line : MG. Quadratic line: DK)

UMBRELLA GROUP



EU NORTH



EU SOUTH

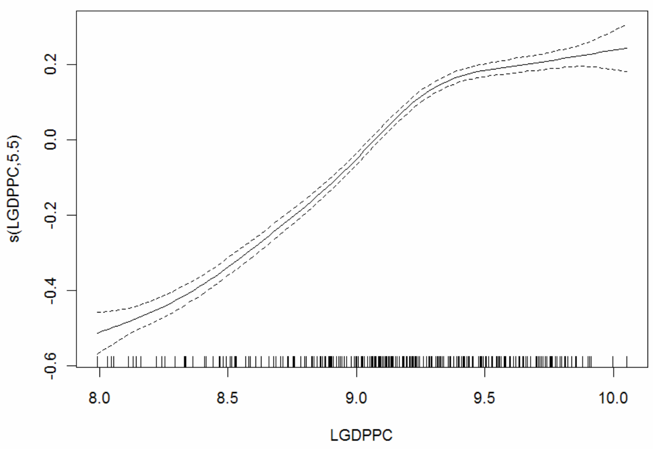
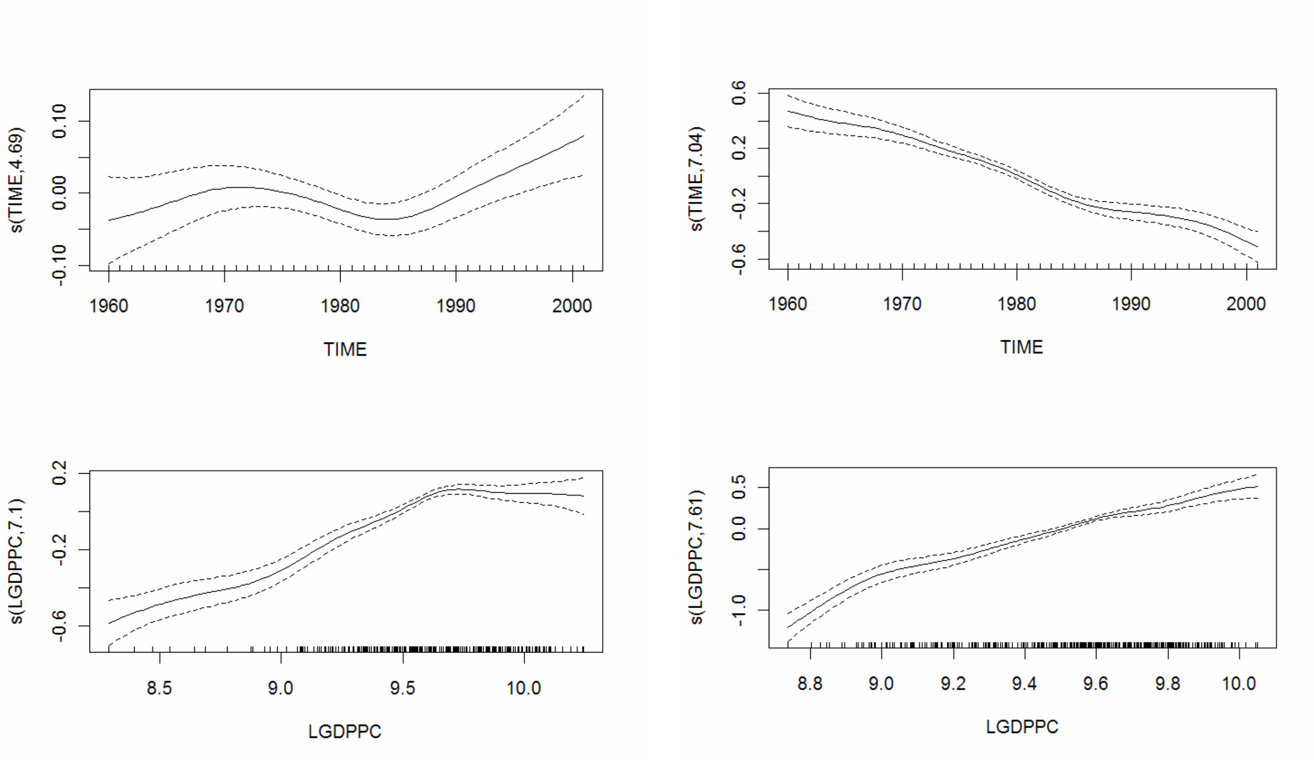


Figure 6 - GAM individual fixed effects (eq 8 with $f(t)=0$)

UMBRELLA GROUP EU NORTH EU SOUTH


s(TIME,4.69)
0.10
0.00
-0.10
1960
1970
1980
1990
2000
TIME
s(TIME,7.04)
0.6
0.2
-0.2
-0.6
1960
1970
1980
1990
2000
TIME
s(LGDPPC,7.1)
0.2
-0.2
-0.6
8.5
9.0
9.5
10.0
LGDPPC
s(LGDPPC,7.61)
0.5
0.0
-1.0
8.8
9.0
9.2
9.4
9.6
9.8
10.0
LGDPPC

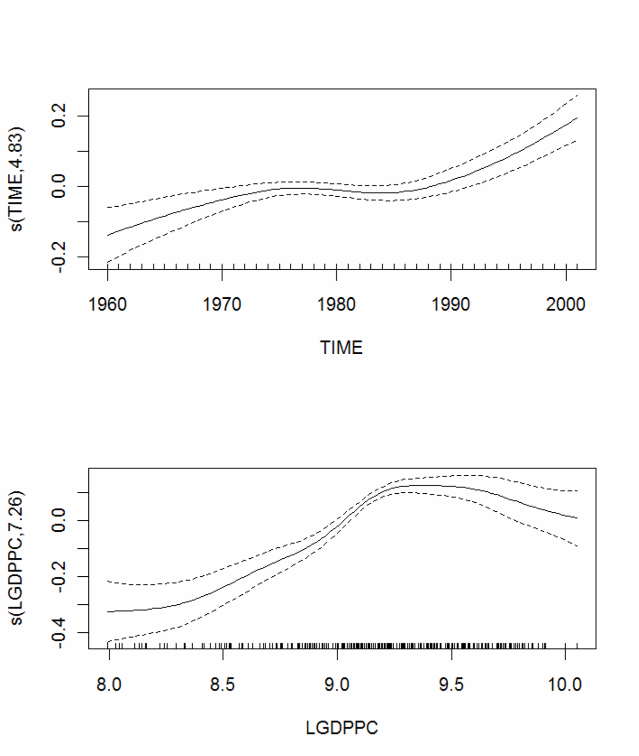
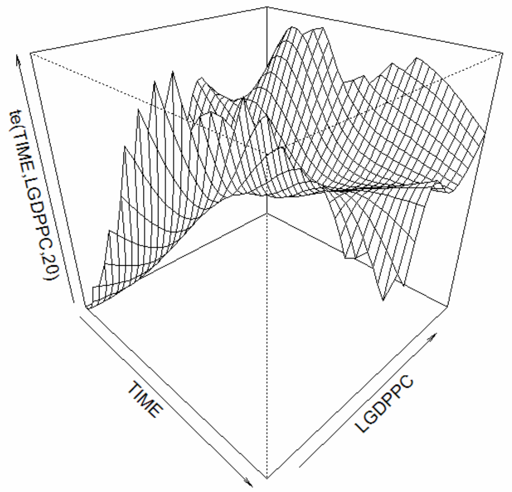
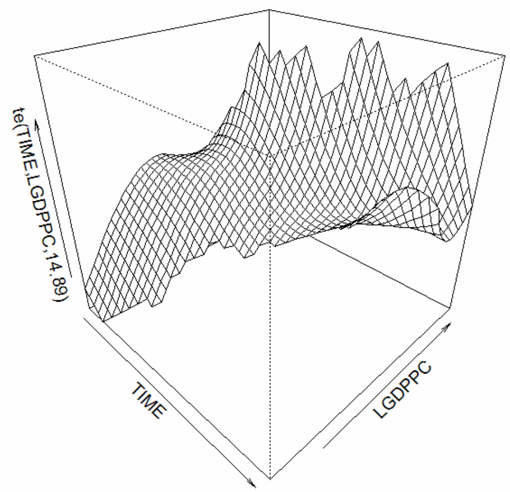


Figure 7 - GAM with individual fixed effects and nonparametric common trend (eq 8)

UMBRELLA GROUP EU NORTH EU SOUTH


te(TIME,LGDPPC,20)
TIME
LGDPPC


te(TIME,LGDPPC,14.89)
TIME
LGDPPC

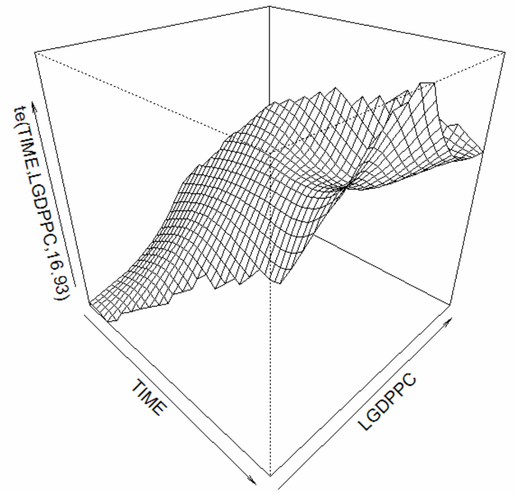


Figure 8. GAM with individual fixed effects and bivariate frame (time, GDP per capita) (equation 9)

Fig. 9 – Intervention analysis. Real and fitted values, Umbrella

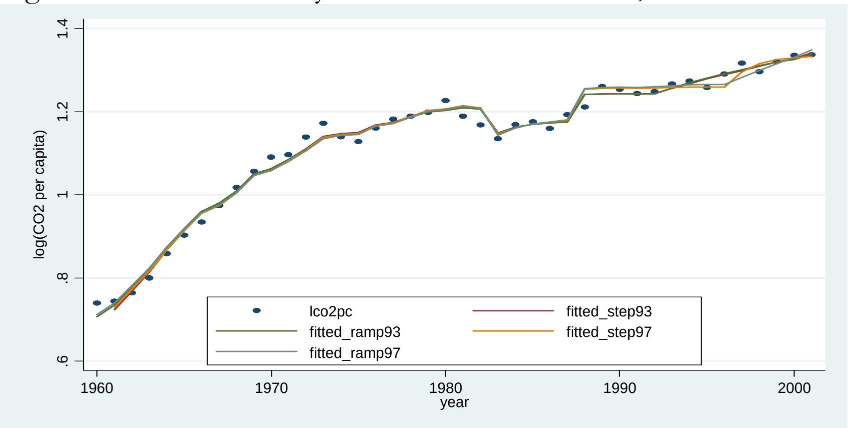


Fig. 10 - Intervention analysis. Real and fitted values, EU south

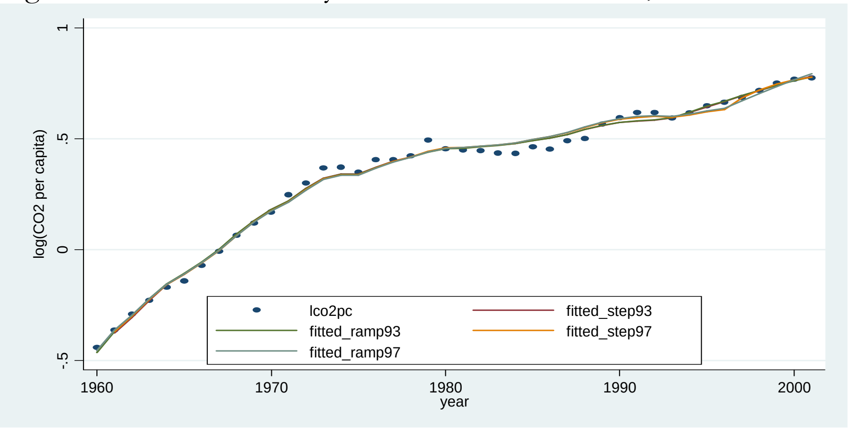


Fig. 11– Intervention analysis. Real and fitted values, EU North