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Income and Time Related Effects in EKC

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INCOME AND TIME RELATED EFFECTS IN EKC

PARAMETRIC AND SEMI PARAMETRIC ANALYSES ON LONG RUN ENVIRONMENTAL KUZNETS CURVES

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Abstract

This paper documents the structural differences between climate change leading `actors' as Northern EU countries, and `lagging actors' - southern EU countries and the `Umbrella group' - with regard to their long run carbon-income relationships. We show that such categorization gives relevant policy and methodological insights. We investigate the issue of cross-country heterogeneity and the heterogeneity biases associated to standard panel data estimates but also disentangle time related and income effects. Parametric and semi parametric panel models allowing for time invariant unobserved heterogeneity robustly 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. Northern EU instead shows bell shapes. The key result is however obtained by estimating a semi-parametric random growth model. Country specific time related factors - that may represent latent innovation and policy features of countries - have been relatively more relevant than income effects in explaining the occurrence of such Kuznets curves. Overall, the countries differ more on their carbon-time relation than on the carbon-income relation which is in almost all cases monotonic positive. Just a few Nordic countries show a bell curve in both income and time related factors.

Keywords: Carbon Kuznets Curves, heterogeneous panels, semi parametric models, random growth, income effect, time related effect

JEL classification: C14, C22, C23, Q53

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Introduction

Many and diversified stylised facts have been proposed on the relationship between pollution and economic development, which became known as the Environmental Kuznets Curve (EKC) hypothesis, a concept that has gained an increasing research attention over time since the pioneering works of Grossman and Krueger (1995), Holtz-Eakin and Selden (1994), Selden and Song (1994) and Shafik (1994). An extensive overview of the main theoretical issues (Anderson and Levinson, 2001) can be found in Borghesi (2001), Stern (2004), Copeland and Taylor (2004) and Brock and Taylor (2010). Then other works followed in providing technology based explanations (Pasche, 2002; Smulders and Bretscgher, 2000; Kelly, 2003; Egli and Steger, 2007; Hartman and Kwon, 2005; Chimeli and Braden, 2009, 2005). A recent survey of theoretical oriented papers is Kijima et al. (2010).

This paper focuses on the CO_2 emission-income relation (CKC, Carbon Kuznets curves) which offers the most robust time series data for applying advanced (long-run) panel data econometric techniques. The relevance of carbon is also depending on the fact that (absolute) decoupling -- that is a negative elasticity in the relationship emissions-economic development - is not (yet) apparent for many important world economies (Musolesi et al., 2010). 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). This is counterbalancing other rather pessimistic views on EKC (Harbaugh et al., 2002; Millimet, List and Stengos, 2003; Wagner, 2006; Furstenberger and Wagner, 2007).

This paper aims to contribute to the development of EKC research in two main directions. First, though policy implications have been sometime linked to the analysis of CKC paths (Cole and Neumayer, 2005), we believe that the literature has not still provided sound policy oriented analysis. In order to accomplish this goal, we make a comparative assessment of CKC shapes for three groups of (quite) homogeneous countries, instead of analysing larger samples of very heterogeneous one as often it happens (mainly OECD or even world wide datasets). We focus on advanced countries subdividing them into the `anti-Kyoto' Umbrella group (a loose coalition of non EU developed countries formed after Kyoto that has sustained a mild approach to climate policy), Southern and Northern Europe, which witness quite different economic and institutional features. We ground our choice on literature review and empirical stylized facts related to environmental policy orientation towards climate change, to environmental innovation patterns and finally to energy structure of the economy. The need to move beyond the provision of `average' evidence towards country specific or grouping of countries has been widely recognised over the recent years (Galeotti et al., 2009), but still rarely made concrete.

Second, from an econometric viewpoint we try to assess how the different issues linked to the estimation of a long-run CKC can affect the results. Indeed, there are three main points to address: the issue of slope heterogeneity, the possible non constrained functional form and the role of unobserved time related factors.

As a benchmark, we begin our analysis by considering only time invariant unobserved omitted factors (as done in many empirical applications) and compare homogeneous and heterogeneous estimators which allow individual slopes to be derived from sampling or Bayesian approaches. This because it is difficult a priori to decide between homogeneous and heterogeneous panel estimators. On one hand, along with the increasing time dimension of panel data sets, some authors suggested the use of heterogeneous estimators (Pesaran and Smith, 1995; Hsiao et al. 1999). This is mainly motivated by the possible heterogeneity bias associated with the use of pooled estimators. 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).

We them remove the parametric constraint (see for instance Azomahou et al., 2006; Azomahou and Mishra, 2008) by adopting a not parametric framework, the Generalized Additive Models (Hastie and Tibshirani, 1990; Wood, 2006). This can be important to capture complex non-linear relations.

Finally and of main concern, we introduce in the model unobserved time related factors which can be correlated with both the emissions and income. This because the standard unobserved (time invariant) heterogeneity specification, is useful only 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 particular, by estimating a nonparametric variant of the random growth model (Heckman and Hotz, 1989, Wooldridge, 2005) we extend the approach by Vollebergh et al. (2009) and show that allowing for country specific unobserved time related factors (rather than common) is relevant both in terms of (econometric) model building and with respect to the economic and policy implications that can be drawn from the analysis.

When considering only time invariant unobserved heterogeneity, we robustly show using both parametric and nonparametric estimators 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 in their monotonic and positive CO_2-income relation. Northern EU instead robustly shows bell shapes across models. However, our results clearly indicate that time related effects have been more relevant than income effects in explaining the occurrence of such Kuznets curves. Such `two sides' evidence is presented for most of the countries, even for those that do not show EKC paths in the end. The EKC is always a net effect, where a monotonic relationship with respect to income is eventually more than compensated by strong negative relationship between (unobserved) time factor and CO_2.

These results allow a policy oriented reasoning and provide a basis to highlight the following two points.

First, they are consistent with the idea that a key reason explaining why some countries supported Kyoto from the beginning and are politically supporting even stricter targets (the 20-20-20 EU plan, the EU resource efficiency strategy) is that they took early actions decades ago in terms of economy restructuring and environmental policies.

Secondly, they confirm the fallacy of the simple EKC adage, for which we show the importance of taking into account for country specific time related factors. This latter result echoes Kuznets himself who rejected the notion of uniform development patterns across time and national contexts an advocated that we needed a clear perception of past trends and of conditions under which development occurred: different contexts create different dynamic patterns, with a special role played by structural changes of the economies (Sirquin, 2010).

The paper is structured as follows. Section 1 presents the frameworks of analysed countries, discussing their differences and homogeneous features; section 2 presents data and some descriptive statistics. Section 3 debates around on the methodology of parametric and semi parametric econometric models sand comments on the main results of the analysis. The final Section concludes with some policy reasoning.

1. Country groups in the Kyoto arena

Three groups of countries are selected, studied and compared in order to go beyond a pure `homogeneous' estimation approach and provide EKC for coherent set of aggregated countries. Environmental policy, eco-innovation and energy (intensity and fuel mix) are key pillars which are behind our categorisation. Groups are:

(a) The `Umbrella group': Australia, Canada, Japan, New Zealand, Norway, U.S.A. this is a set of `anti Kyoto' countries, or rather countries willing to adopt flexible instruments (such as joint implementation, clean development mechanisms) rather than stringent and specific national policies (carbon taxes, emission trading) in order to achieve climate change related international and national goals.

(b) The 'European Union (EU) North': Belgium, Denmark, Finland, France, Germany, Netherlands, Sweden, U.K. those are the relatively more climate change policies supportive countries.

(c) The 'EU south': Austria, Greece, Ireland, Italy, Portugal, Spain. Those are the countries that were still relatively over `development oriented paths', and less in favour of stringent climate policies and targets.

First, as far as environmental policy is concerned, various evidence revolving around environmental policy commitment and policy stringency is in favour of our aggregation choice. Before and after Kyoto and Rio Convention, the northern EU countries behave quite differently with respect to climate change policies. Scandinavian 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. The UK and Germany than followed. Ecological tax reforms (Andersen and Ekins, 2009) are instead still absent both from most if not all (a) and (c) groups for various reasons. Data on environmental tax revenue on GDP (EUROSTAT) in fact shows that only Scandinavian countries and the Netherlands historically present figures larger than 3% of GDP (and 6% to total taxes, with Denmark at 11% and UK at 6.5%), with differences that were larger in the 80's and 90's. The UK has recently strongly increased the share on GDP though more diffuse use of environmental taxes. Those include energy taxes, which often are implemented as indirect environmental taxes. The picture on pollution taxes is even more striking. The (b) group accounts for more than 80% of EU total revenue in 1995. The dynamic has not changed since the past periods, with striking examples such a Denmark, a country that collects in environmental taxes 20 times the amount of Italy (4 billions Euros), that has a much larger GDP. The usually exploited `environmental policy stringency index' (World Economic Forum Executive Opinion survey) reinforce our argument. A recent OECD paper (Johnstone at al., 2010) shows that (over 2001-2007) stringency is higher in Germany, Denmark, Sweden, with most of (b) having a value higher than 6 (1-7 index), Canada, Japan and US in the middle of the table and Greece, Spain and Italy showing index lower than 5 in an area where some less developed countries stay. In terms of `stability and transparency' of environmental policy regimes the picture is even striker: the cluster of (b) is in the highest part, the (a) group lies in the middle, with the US bad positioned, and main countries of (c) lagging behind. Some overlapping occurs, but in the end the (a-b-c) categories are coherent with the environmental policy structural history.

Eco-innovation. Recent studies (among others, Johnstone, Hascic and Popp, 2010, Johnstone et al., 2008; Johnstone and Labonne, 2006; Popp, 2002; Brunnermeier and Cohen, 2003) have presented various evidence on the relation between environmental regulations and green innovations. It is interesting, in examining the trend of EPO patent applications in renewable, that the German leadership begins in the late 80's (a period when Germany started to strengthen its environmental policy commitment then influencing most EU Directives) and consolidates in the 90's. The (expected, as big countries) role of Japan and US is significant, but it is overwhelmed by Germany if one takes into account GDP and population differences. Taking account of size, the Denmark performance is also outstanding (Popp et al., 2010). Air pollution abatement technologies also shows a dominance of Germany over the US, which has increased since the early 80s, with France closing the gap as well. Overall, the 90's seems to have anticipated the Kyoto protocol, insofar air pollution, clean coal and renewable technologies massively increased, reaching a peak of the trend in 2001. As shown by Dechezlepretre et al., 2011), the increase of climate change patents as a world share is correlated to oil prices and shows a great momentum in the 90's. Trends and increases were much different for other green technologies (Johnstone et al., 2010). Within the EU, the established innovation scoreboard (European Commission, 2009) places Italy, Spain, Greece and Portugal as moderate innovators, and Germany, Sweden, Denmark, Finland (Norway instead presenting a low index) and UK as leaders. R&D figures also shows a strong divide between northern and southern EU countries. Turning the head to a more global picture, we note that considering again climate friendly patent trends (1978-2006) (Dechezlepretre et al., 2011), while Japan, Germany and the US rank first in terms of patenting activity (EU27 weights 27%), it must be noted that EU weights more than North America and Japan if one looks at inventions that are patented internationally (capturing innovation quality and diffusion .

Germany is now first with 22%, UK 6%, US 13%). The 6% of world share attributed to the sum of France, the Netherlands and the UK is also knowledgeable. In per capital terms the EU leads the picture. Similarly to environmental policy issues, some overlapping occurs, but in the end the (a-b-c) categories are coherent with the (eco) innovation history of the considered countries in terms of homogeneity within the observed OECD internal differences.

As third point we may consider is related to energy issues. In overall, a decrease of energy use per GDP terms is observed for main and richest OECD countries in the recent past (Geller et al., 2006), with even US and Norway leading the path. Japan, US and main EU countries performances are strongly correlated over 1973-1998. Somewhat differently, we note that energy efficiency of fossil fuel production awards the northern EU (but also Italy, having historically high energy prices) with respect to Canada and the US. The fuel input mix is also relevant for understanding structural factors behind macro energy efficiency. As example, recent evidence shows that the coal share is significantly reducing energy efficiency and knowledge accumulation (patents) increasing it (Verdolini et al., 2010). The observation of coal and renewable shares highlights differences. The change in coal-based energy use over 1970-2001 (International Energy Agency energy balances sources) is of -26% for OECD Europe and +90% for OECD North America (comparable in GDP terms), with meaningful details for our reasoning (Australia +130%, US +81%, Canada +82%. The EU witnesses striking different performance (Austria -18%, UK -56%, France -66%, Germany -41%, while `developing EU countries' such Spain +112% and Greece +600%. We also mention exceptions in the North like Denmark historical reliance on coal (Jacobsen, 2000), + 92%, Sweden +30%). As far as renewable sources are concerned, primary energy supply tables show similar increases for solar/wind that are so massive to be difficultly commendable in the long run. We note that comparing Europe and North America, the 2001 ratio of installed energy supply is 3:2; strikingly lower than that of 1983 (OECD North America was nearly to 0), but still significant. Perhaps due to the complexity of the energy issue, the disaggregation of countries in a-c groups is here less clear cut than above. Nevertheless, insights on fuel mix and renewable shares depict differences that provide coherence to the selection and grouping of countries.

2. The Data

Data on emissions are from the database on global, regional, and national fossil fuel CO2 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. Data on GDP per capita in 1990 International `Geary-Khamis' dollars are from the database managed by the OECD.

For our study we use the subset of emission data that matches the available time series on GDP per capita on the basis of joint availability, series continuity, and country definitions. This resulted in a sample which covers a longer period (1960-2001). Table 1 below summarises the main variables used and the descriptive statistics. The Umbrella group presents the highest average level of both CO2 per capita (expressed in terms of tonnes per capita) and GDP per capita (3.14 and 15,143, respectively) while southern European countries are characterised by the lowest average levels of such variables (1.48 and 10,215). The northern European countries have a similar average level of GDP per capita (14,203) compared to the Umbrella group but are characterised by lower levels of emissions (2.61). 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 CO2-GDP is quite homogenous within each group: it is clearly monotonic (eventually non linear) for the Umbrella group and for EU-South but shows an inverted U shape for EU-North countries.

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	0.91	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	4,265.277	2,955.836	23,201.45

T= 1960-2001; CO_2 per capita in t/pc; GDP per capita in 1990 International 'Geary-Khamis' dollars

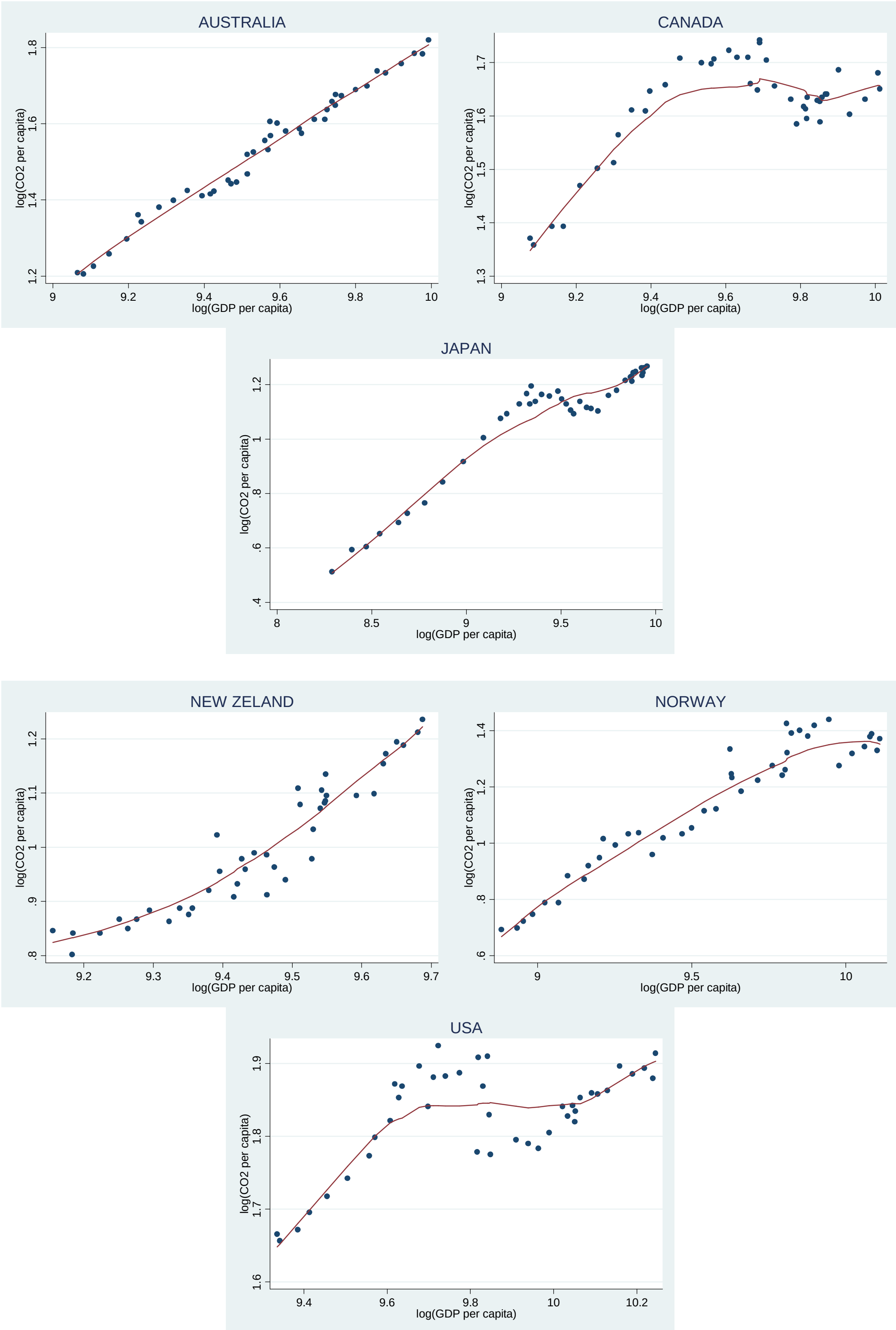


Figure 1. UMBRELLA countries (scatter : real values. Line : robust locally weighted scatterplot smoothing)

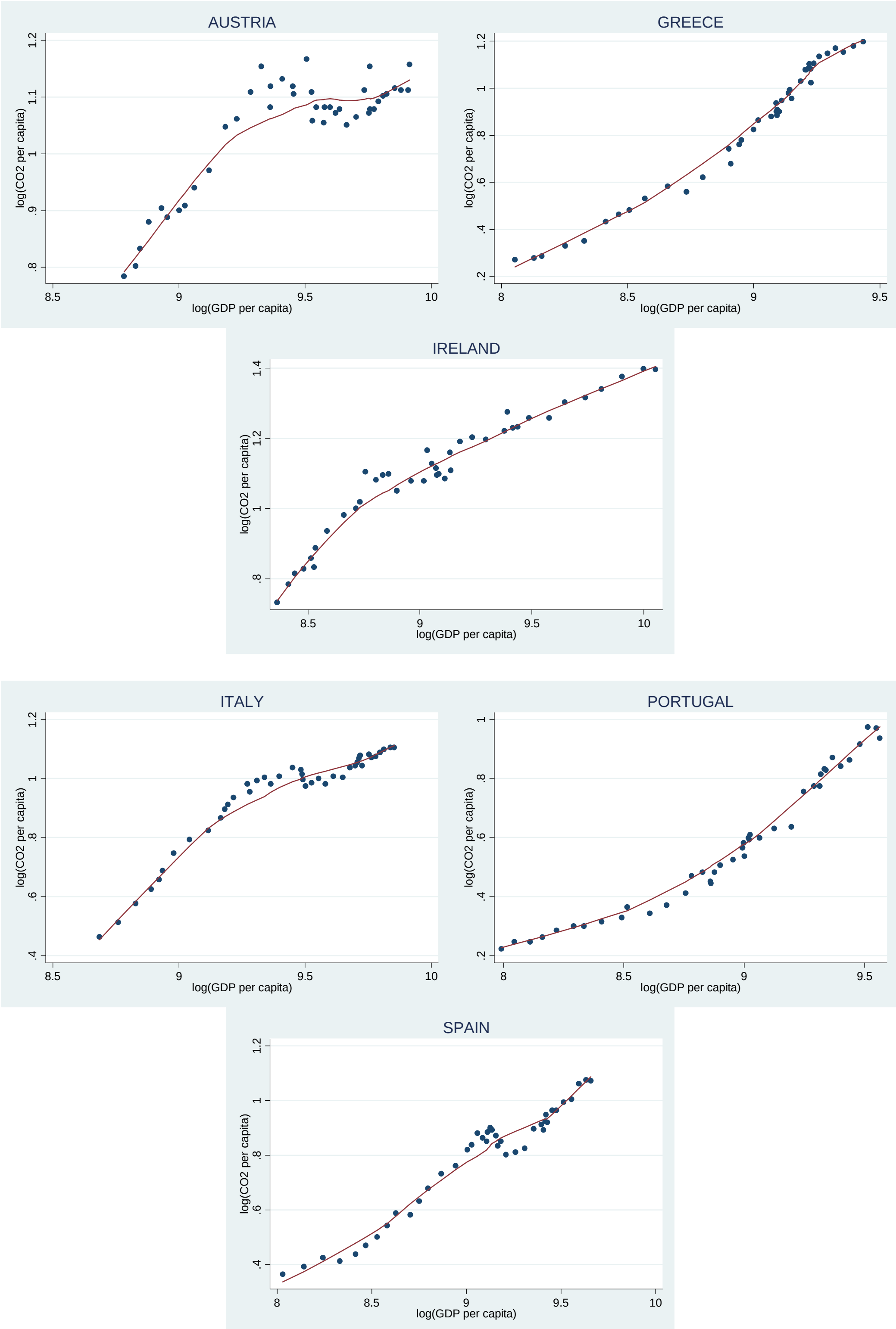


Figure 2. EU-SOUTH countries (scatter : real values. Line : robust locally weighted scatterplot smoothing)

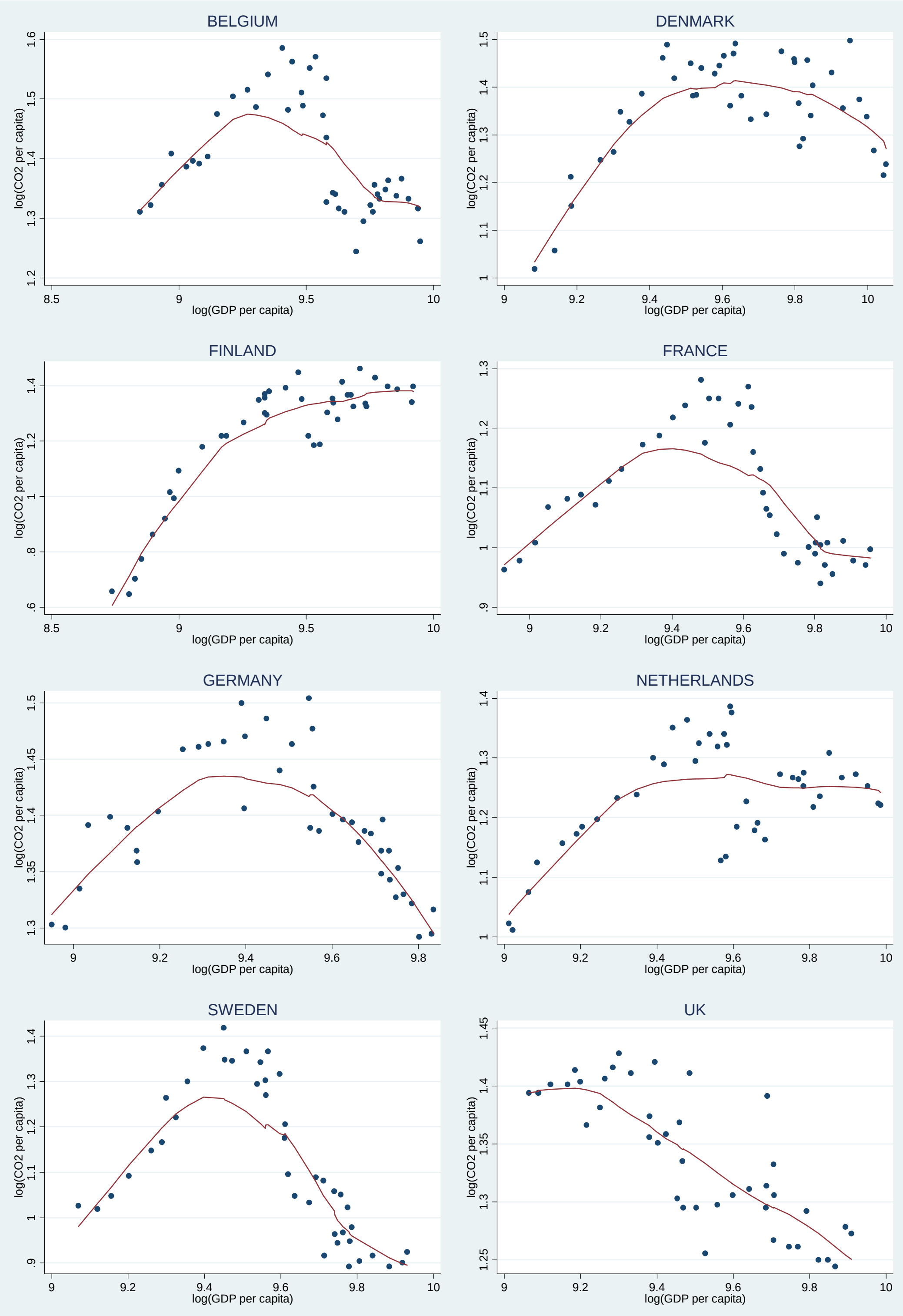


Figure 3. EU-NORTH countries (scatter : real values. Line : robust locally weighted scatterplot smoothing)

3. Econometric analyses: heterogeneity and time related factors

Following the recent EKC related literatures, 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; $i \in \Gamma$, and Γ is the set of cross-section units $\Gamma=\{1,2,\ldots,N\}$ and $t \in \Lambda=\{1,2,\ldots,T\}$ indicates time series observations. A general and, at the same time, an identifiable EKC specification is given by assuming that the income effect, the effect of (time invariant) unobserved heterogeneity, the effect of time and the idiosyncratic effect are separable:

$$y_{it}=c_{i}+f(x_{it})+g(t,i)+\varepsilon_{it} \quad (1)$$

where the effect of the time invariant unobserved variables is captured by introducing individual- fixed effects, $c_{i}\in\mathbb{R}$, the function $f:Y\rightarrow\mathbb{R}$ captures the effect of income on CO_2 emissions (Y denotes the set of possible values of x_{it}) while the effect of time (eventually heterogeneous across countries) is measured through the function $g:\Gamma\times\Lambda\rightarrow\mathbb{R}$ and ε_{it} is an idiosyncratic error term. The main issues in terms of econometric modelling rely on the speciation of $f(x_{it})$ and $g(t,i)$.

The most adopted specification in early studies is constrained, i.e. assuming that $g(t,i)=0$ and imposing to $f(x_{it})$ a parametric form with homogeneous slopes across countries (Cole et al., 2003; 1997).

First, with respect to $f(x_{it})$, it could be useful to remove the constraint that $f(x_{it})$ is homogeneous across countries (Musolesi et al., 2010). This may avoid the so called heterogeneity bias (Hsiao, 2003). Moreover, in order to obtain a more precise estimation of the shape of the function some researchers pointed out the relevance to adopt a not parametric framework (Azomahou et al., 2006; Azomahou and Mishra, 2008).

Secondly, let us focus on the restriction $g(t,i)=0$. Such a constraint is motivated by the following reasons: it allows for a greater comparability with existing studies and, maybe more important, , 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, imposing $g(t,i)=0$ might be not appropriate because it leads to an omitted time related factors bias. Recently, Vollebergh et al. (2009) estimated eq. 1 without imposing a parametric formulation for $f(x_{it})$ and introducing unobserved time related factors which are assumed to be common to specific groups of countries.

In the following, we provide alternative specifications for both $f(x_{it})$ and $g(t,i)$. This allows us to understand how the issues of slope heterogeneity, non constrained functional form and time related unobserved factors affect the estimation of the CKC for the three groups of countries under study. Though analysing both income and time related variation cross groups and countries, we will devote attention to individual time related factors that could explain the overall EKC dynamics emerging from country aggregations.

3.1 The benchmark parametric specifications and slope heterogeneity

First, let us suppose that $g(t,i)=0$ (such restriction imply focusing on the global effect of GDP on CO_2) and that $f(x_{it})$ can be approximated with a polynomial function. In such a parametric panel data context a relevant but tricky issue is choosing between homogeneous and heterogeneous estimators. On one hand, 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 since per capita GDP presents high variation across countries. 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). Finally, 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).

We employ the following "homogeneous estimators" (Table 2): the Least Square Dummy estimator (FEM) allowing for individual fixed effects, as basis and with the standard errors calculated using the formula by the Driscoll-Kraay (1998) which corrects the variance-covariance matrix for the presence of serial as well as spatial correlation. Indeed, the Cross Dependance (CD) test (Pesaran, 2004), strongly rejects the null hypothesis that the errors are independent across countries. For this reason we also estimate the model using the GLS slopes constrained Seemingly Unrelated Regressions estimator (SUR, Zellner, 1962). Then we use 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.

Next, we apply 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. Then we use the Mean Group (MG) estimator proposed by Pesaran and Smith (1995) for dynamic models. It is defined as the simple average of the OLS estimators relative to the individual equations expressed in ARDL; the hierarchical Bayes approach (HB, 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 but in practice it might be preferable to other estimators (see also Baltagi et al., 2004). Finally, the shrinkage estimators described in Maddala et al. (1997), that is, the Empirical Bayes (EB) and the Iterative Empirical Bayes (IEB) 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. Tables 2 and 3 present the estimation results starting from a quadratic specification and the model reduction is made by excluding non significant quadratic terms. This is a standard `from general to particular' procedure in time series analyses for arriving at the most economic and statistical significant specification. For each employed estimators, we examine the three samples of countries in terms of carbon-income shape (elasticity) and eventual EKC turning point (TP), assessing whether this turning point (TP) is within or outside the range of observed values.

All the homogeneous estimators (table 2) show that quadratic specifications are significant for all the analysed groups. Nevertheless, the evidence is different across groups: while the TP for EU north ($11,491-$14,030) is within the range of observed values this is not the case for the Umbrella group and EU south, which show similar TPs, largely outside the observed range of observations.

Table 2 – Homogenous estimators

	UMBRELLA			EU NORTH			EU SOUTH		
	FEM	SUR	PMG	FEM	SUR	PMG	FEM	SUR	PMG
LGDPPC (linear)	3.716	3.072	3.041	16.888	15.202	12.846	2.862	2.498	3.117
	(5.97)	(15.133)	(2.067)	(9.96)	(26.165)	(5.375)	4.87	13.287	(4.485)
LGDPPC (quadratic)	-0.173	-0.138	-0.126	-0.890	-0.796	-0.687	-0.132	-0.113	-0.152
	(-5.23)	(-12.54)	(-1.65)	(-9.89)	(-25.67)	(-5.452)	(-4.14)	(-11.30)	(-4.000)
EKC shape	inverted U	inverted U	inverted U	inverted U	inverted U	inverted U	inverted U	Inverted U	inverted U
Turning point ($1990)	46,160.715	68,216.025	174,113.091	13,195.623	14,030.586	11,491.294	51,067.782	63,139.216	28,375.730
Turning point range	Out	out	out	in	in	in	out	out	out

t statistics in brackets. L indicates log (LGDPPC=log(GDP per capita)). FEM: Fixed Effects Estimator (Driscoll-Kraay covariance matrix). SUR: GLS slopes constrained Seemingly Unrelated Regressions estimator. PMG: Pooled Mean Group estimator.

Table 3 – Heterogeneous estimators

	UMBRELLA					EU NORTH					EU SOUTH				
	Swamy	MG	HB	EB	EIB	Swamy	MG	HB	EB	EIB	Swamy	MG	HB	EB	EIB
LGDPPC (linear)	0.473 (4.778)	0.475 3.006	3.600 (36.327)	0.473 (4.827)	0.473 (4.876)	17.492 (4.135)	12.262 (4.966)	17.494 (201.080)	17.470 (4.330)	17.287 (4.791)	0.464 (6.705)	0.436 (4.955)	2.178 (25.326)	0.465 (6.838)	0.465 (6.838)
LGDPPC (quadratic)			-0.163 (-3.630)			-0.922 (-4.229)	-0.654 (-5.070)	-0.922 (-36.888)	-0.920 (-4.319)	-0.912 (-4.800)			-0.088 (-2.667)		
EKC shape	monotonic	monotonic	inverted U	monotonic	monotonic	inverted U	inverted U	inverted U	inverted U	inverted U	monotonic	monotonic	inverted U	monotonic	Monotonic
Turning point ($1990)			62,501.4			13,172.68	11,785.41	13,159.87	13,287.32	13,062.78			23,6806.82		
Turning point range			out			in	in	in	in	in			out		

t statistics in brackets. L indicates log. (LGDPPC=log(GDP per capita)). SWAMY: Swamy's random coefficient estimator. MG: Mean Group estimator. HB: Hierarchical Bayes. EB: Empirical Bayes. EIB: Empirica Iterative Bayes.

The comparison of the five heterogeneous panel data estimators (table 3) presents slightly different evidence, which provides insights into economic and methodological perspectives. First, they confirm the existence of an inverted U relation in the case of northern European countries with TPs that are very close to those obtained imposing slope-homogeneity. However, for both the Umbrella group and southern European countries, most heterogeneous estimators provide evidence of a linear CO2-GDP relationship. The estimated elasticity is always slightly lower than 0.5, which is a sign of relative de-linking. It could be also interesting to note, in the light of the results by Baltagi et al. (2004), that the hierarchical Bayes estimator provides results that are very close to those obtained when using homogeneous estimators.

The applied estimators cover a wide range of possibilities, regarding the heterogeneity in the slope -and others relevant - parameters, the dynamic behaviour (the PMG, MG are model with an autoregressive and distributed lags structure) and the cross sectional and serial dependence. They provide a very robust evidence of an inverted U relation for the northern European countries, and basically reproduce what depicted in fig 1-3. We finally show in table 4 the results obtained on the full sample of countries. In this case, both homogeneous and heterogeneous estimators indicate that estimating the model on the full sample would erroneously provide evidence of a CKC. It therefore additionally gives a clear indication about the relevance of the adopted countries' categorization and the importance of looking into specific (individual) effects associated to income and time effects.

Table 4. Full sample's estimates

	ALL COUNTRIES	
	FEM	SWAMY
LGDPPC (linear)	4.804 (5.99)	8.616 (3.04)
LGDPPC (quadratic)	-0.240 (-5.51)	-0.437 (-2.87)
EKC shape	inverted U	inverted U
Turning point ($1990)	21,371	18,898
Turning point range	in	in

t statistics in brackets. L indicates log (LGDPPC=log(GDP per capita)). FEM: Fixed Effects Estimator (Driscoll-Kraay covariance matrix). SWAMY: Swamy's random coefficient estimator.

3.2 Non constrained functional form and common time effect

The main limitation of the above mentioned parametric approaches we used as benchmark is that they hardly capture non-linear complex relations that cannot be easily approximated with a polynomial function. This is relevant in our study (see fig. 4 for Umbrella group, other figures are available upon request).

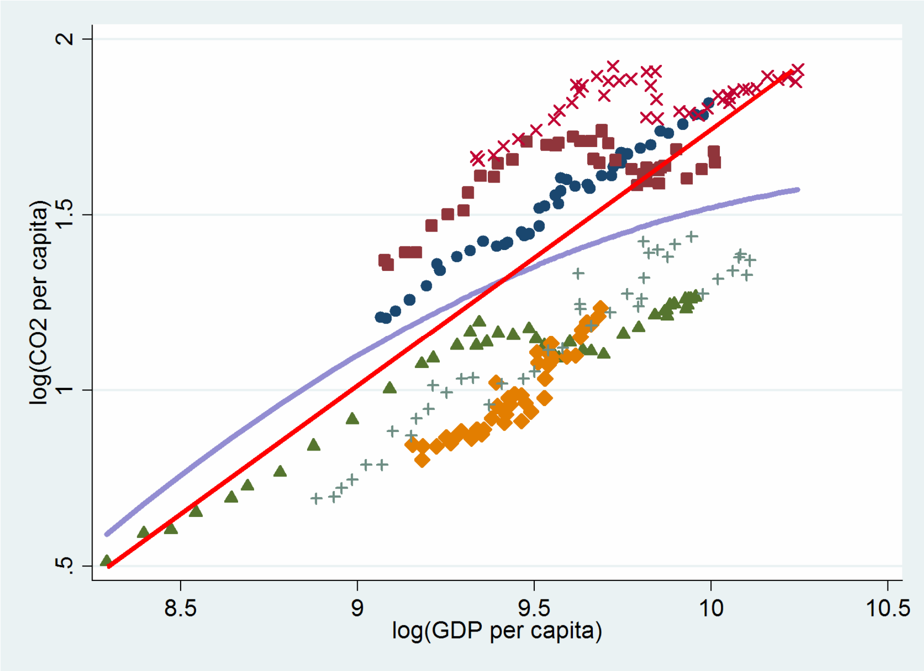


Figure 4. Umbrella countries: real and fitted values with homogeneous (FEM) regression and heterogeneous (SWAMY)

(scatter : real values. Straight line : SWAMY. Quadratic line: FEM)

We consequentially estimate the function $f(x_{it})$ adopting a semi parametric approach and in particular, given the additive structure of our panel specification, the Generalized Additive Models (GAM, Hastie and Tibshirani, 1990; Wood, 2006) can be an useful framework for the analysis (Azomahou and Mishra, 2008). The eq. 1. constraining g(t,i)=0 as in the previous section is thus re-estimated semi-parametrically using the R package "mgcv". The model is estimated by penalized maximum likelihood. Let consider a semiparametric (generalized) additive model of the form:

(2) $E(y_{i})=\mu_{i}$ and $g(\mu_{i})=\eta_{i}\equiv z_{i}'w+f_1(x_{1it})+f_2(x_{2it})+\ldots,$

where $y_{i}\sim$ an exponential family distribution, g is a monotonic link function, $z_{i}'w$ is the parametric part of the model and the f_{j} are smooth functions of the covariates x_{j}, such a model is estimated by maximizing:

(3) $l(\eta)-(1/2)\sum\theta_{j}\int[f_{j}''(x)]^2dx$

where l is the log-likelihood of the linear predictor, the terms in summation serve to penalize models with excessively complicated component functions with the parameters θ_{j} which control the trade-off between model fit and model smoothness. In practice, the penalized likelihood is maximized by penalized iteratively reweighed least squares (P-IRLS) (Wood, 2004). How to estimate these smoothing parameters θ_{j} and how to represent the smooth functions f_{j} are the main issues to deal with. Thin Plate Regression Spines (TPRS) are adopted as a basis to represent the smooth terms f_{j}, since they have some optimality properties (Wood, 2003). The smoothing parameters θ_{j} are selected directly using the so called outer iteration (Wood, 2008) which it has been shown to be computationally efficient and stable and adopt the GCV (Generalised Cross validation) criterion. The estimation results for the nonparametric part of the model are in table 5 below (column "IFE", Individual Fixed Effects) where for each smooth term there are reported the estimated degrees of freedom and the corresponding p-value whereas the resulting plots of the smooth terms (with their confidence intervals) are depicted in fig. 5.

Table 5 - Semi-parametric estimation

	UMBRELLA				EU NORTH				EU SOUTH			
	"IFE"	"IFE_CT"	"IFE_IT"	"IFE_IT_IS"	"IFE"	"IFE_CT"	"IFE_IT"	"IFE_IT_IS"	"IFE"	"IFE_CT"	"IFE_IT"	"IFE_IT_IS"
SMOOTH	Edf(p)	Edf(p))	Edf(p)	Edf(p)	Edf(p)	Edf(p))	Edf(p)	Edf(p)	Edf(p)	Edf(p))	Edf(p)	Edf(p)
LGDPPC	7.13 (2e-16)	4.69 (6.25e-06)	1 (2e-16)		6.59 (2e-16)	7.04 (2e-16)	1.28 (3.6e-12)		5.50 (2e-16)	4.83 (1.39e-12)	3.87 (2e-16)	
TIME		7.10 (2e-16)				7.61 (2.73e-05)				7.26 (2e-16)		
TIME_AUSTRALIA			1 (0.42)	6.62 (0.011)								
TIME_CANADA			7.00 (2e-16)	5.96 (2e-16)								
TIME_JAPAN			5.97 (2e-16)	5.26 (2e-16)								
TIME_NEWZELAND			8.14 (4.89e-13)	8.18 (1.98e-15)								
TIME_NORWAY			8.70 (2e-16)	7.42 (8.20e-06)								
TIME_USA			5.85 (2e-16)	6.10 (2e-16)								

TIME_BELGIUM	6.42 (2e-16)	6.81 (2e-16)		
TIME_DENMARK	6.85 (2e-16)	7.56 (5.37e-08)		
TIME_FINLAND	8.51 (2e-16)	9 (3.59e-09)		
TIME_FRANCE	4.95 (2e-16)	5.21 (2e-16)		
TIME_GERMANY	2.87 (2e-16)	2.38 (8.97e-11)		
TIME_NETRHERLANDS	5.86 (2e-16)	3.65 (3.88e-11)		
TIME_SWEDEN	8.06 (2e-16)	8.56 (2.10e-11)		
TIME_UK	1 (2e-16)	1 (5.30e-06)		
TIME_AUSTRIA			4.97 (2e-16)	1 (0.0013)
TIME_GREECE			4.78 (2e-16)	4.61 (2e-16)
TIME_IRELAND			6.18 (2e-16)	5.74 (2e-16)

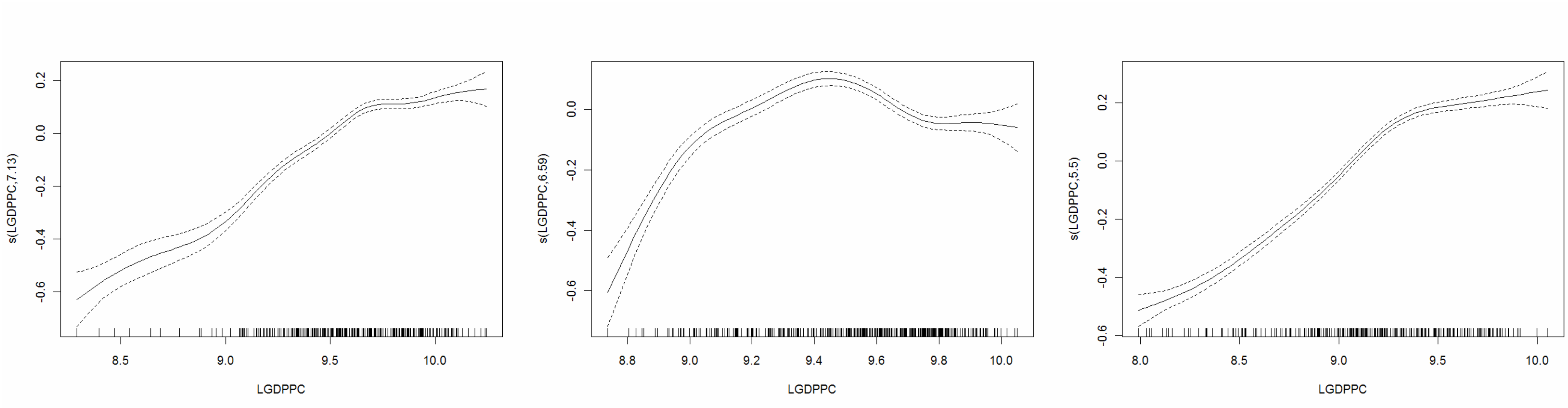
TIME_ITALY			5.18 (2e-16)	4.99 (2e-16)
TIME_PORTUGAL			1 (3.48e-05)	1 (8.59e-05)
TIME_SPAIN			6.39 (2e-16)	4.51 (0.0808)
LGDPPC_AUSTRALIA	1 (.056)			
LGDPPC_CANADA	1 (.156)			
LGDPPC_JAPAN	1 (1.01e-12)			
LGDPPC_NEWZELAND	1 (0.012)			
LGDPPC_NORWAY	5.67 (0.018)			
LGDPPC_USA	1 (1.32e-05)			
LGDPPC_BELGIUM		1 (8.40e-05)		
LGDPPC_DENMARK		6.81 (1.45e-06)		

LGDPPC_FINLAND	4.62 (2.27e-05)	
LGDPPC_FRANCE	1 (1.17e-05)	
LGDPPC_GERMANY	1.28 (6.38e-05)	
LGDPPC_NETRHERLANDS	5.20 (1.28e-06)	
LLGDPPC_SWEDEN	2.74 (.39)	
LGDPPC_UK	1 (3.23e-05)	
LGDPPC_AUSTRIA		4.70 (2e-16)
LGDPPC_GREECE		1 (0.0010)
LGDPPC_IRELAND		1 (0.0012)
LGDPPC_ITALY		1 (1.45e-05)
LGDPPC_PORTUFAL		3.28 (1.08e-07)

LGDPPC_SPAIN												5.39 (0.0089)
AIC	-639.21	-672.85	-1102.64	-1148.41	-659.70	-776.07	-1240.65	-1331.64	-677.44	-745.67	-1192.58	-1201.58
BIC	-593.85	-606.53	-944.99	-946.50	-600.19	-685.81	-1031.54	-1038.39	-633.33	-678.31	-1053.63	-1041.80

L indicates log (LGDPPC=log(GDP per capita)). Edf indicates estimated degrees of freedom. (p) is the p-value. TIME_ “NAME OF THE COUNTRY” is a"factor-by-curve interaction" i.e. the interaction between the common trend and the country's indicator variable. LGDPPC_ “NAME OF THE COUNTRY” is a "factor-by-curve interaction" i.e. the interaction between log(GDP per capita) and and the country's indicator variable. AIC:

UMBRELLA GROUP EU NORTH EU SOUTH



Notes. s(LGDPPC, edf) indicates the estimated smooth function (and its 95% confidence interval) of log (GDP per capita) ($f(x_{it})$ in eq. 1) and edf represents the estimated degrees of freedom.

Figure 5 - GAM with individual fixed effects but no trend ($g(t)=0$)

The results clearly indicate that all groups of countries present nonlinear and quite complex CO_2-GDP relation (the edf being 7.13, 6.59 and 5.50 for the Umbrellas, EU-North and EU-South, respectively). Once again, Umbrella and EU-South present a monotonic relation whereas for EU NORTH the CO_2-income relation is not monotonic. These results, thus, are on the one hand quite similar to those commented on above for parametric panel models, in terms of economic significance, but on the other hand at the same time highlight the limits of parametric formulations. In fact, EKC dynamics mostly look non linear and complex, worth being investigated further.

On that basis, we next follow Vollebergh et al. (2009) and allow unobserved common factors, such as oil price (shocks), environmental policy stringency, innovation intensity etc, to affect homogeneously the level of emissions. A relevant difference with respect to Vollebergh et al. (2009) is that adopting a GAM framework allow us to focus our attention also on the CO_2-time relation rather than only looking at the "net" CO_2-GDP relation. We remark again that both structural innovation/energy factors and the stringency of policy implementation that characterise a country or a group of homogenous countries might be relevant in explaining EKC dynamics. In addition, how different areas of the world and countries reacted to exogenous events such as, among others, oil shocks and environmental global conventions, is a possible content to be considered when analysing long run carbon-income relationships. Such `time related effects' may weight more than strict economic ones. Another approach could be well that of including additional covariates that capture innovation, energy and policy issues. This choice was nevertheless ruled out since it restricts the time span of observations and we aim at analysing long run scenarios.

The analysis is implemented by introducing a common (non parametric) trend of the kind:

(4) $y_{it}=c_{i}+f(x_{it})+g(t)+\varepsilon_{it}$

The outcomes with group's specific non parametric temporal trend now present a very different picture (table 5, column "IFE_CT", Individual Fixed Effects and Common Trend, and fig. 6). Indeed, the CO_2-GDP 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, and is now monotonic and positive for EU NORTH. The relation between emissions and the time factor is instead positive for UMBRELLA and EU SOUTH and significantly negative for EU NORTH.

Even more relevant, these results show that the overall time evolution of per capita emissions is driven more by the unobserved common factors related to various time effects, rather than by economic development per se.

Such evidence, though somewhat counterintuitive at first sight, provides a clear evidence that the common time related factors bias is empirically important and in the meanwhile adds more insights , that are the corner stone of our analyses. First, southern EU countries actually show some signal of delinking related to income, not time. This may appear counterintuitive but it is not. It could well be explained by the observed decrease in energy intensity of GDP in some countries and by some structural production and consumption features that influence GHG/GDP ratios. Italy, as example, 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 of energy utilities) may lead the GDP related delinking within this group of countries. Its energy efficiency was historically high (Arigoni Ortiz et al., 2008). Austria, that possess nuclear, is another case in support of the argument. It would then be worth looking more in depth into country specific non common factors as we will do later.

The same reasoning applies to Umbrella countries. Some per capita emission stabilization is witnessed, and in addition the `time component' appears to exert $CO_2$ reduction only up to the mid 80's. The `sustainability' policy era beginning in 1987 with the UN Brundtland Commission, followed by the 1992 Rio convention, was possibly not impacting as possible `exogenous' time event, while oil shocks likely had some effects.

As said, an apparently counter intuitive but reasonable enough evidence, that gives support to further investigations, is also that related to northern EU. In fact, when disentangling income and time effects, northern EU shows an increasing emission relation with respect to GDP. 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 effects (over the all period, from the energy shock in the 70's 80's to the environmental policy era in the 90's). Some well known stylized facts can be advanced to explain such results. A strong pattern of green technological investments in some countries, exemplified primarily by Germany and also by UK/Scandinavian performances above all, which often intertwined with (higher than average) stringency of environmental policies. The `induced innovation' effect of environmental policy could be at stake here (Jaffe et al., 1995; Jaffe and Palmer, 1997; Barker et al., 2009). Environmental policy and taxation can well induce emission reductions through innovation inducement if effectively and efficiently applied (Millock and Nauges, 2006). Scandinavian countries were in fact the only ones to implement full ecological tax reforms in the early 90's with the aim to achieve `double dividends' (Aidt, 2010, Andersen and Ekins, 2009; Andersen et al., 2007), later followed by some experiences of ETR in Germany, UK (Agnolucci, 2009), The Netherlands Overall, certain homogeneity in the performances of the three different groups is robustly noticed as far as the time related features of the EKC are concerned. This was expected and supports our categorisation. Nevertheless, some country specific idiosyncrasies still remain possibly relevant, especially behind the common time trends

<footnote>Though some works that analyse country or regional differences have developed (Musolesi et al. (2010) note that just for three of the five analysed sub-samples (G7, EU15, OECD) the EKC hypothesis is robust; other recent works 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; Cole, 2005, 2003; Galeotti et al., 2006, 2009), there is lack of investigation at country specific level. Among others, List and Gallett (1999) apply SURE techniques for analysing US long run emissions by state. Some EU heterogeneity in EKC performances is found and discussed in Galeotti et al. (2009), who analyse data up to 2002. Individual country effects thus have been relatively unexplored.

3.3 A nonparametric random growth model

More flexibility can be obtained by allowing an individual time trend as in Heckman and Hotz's (1989) random growth model : $g(t,i)=\gamma_{i}t$. Wooldridge (2005) provides very useful methodological insights while Papke (1994) and Friedberg (1998) are examples showing empirically how important can be to allow for individual specific trends. A motivation of such specification is that it allows (c_{i},γ_{i}) to be arbitrarily correlated with x_{it}. This can certainly relevant when x_{it} is an indicator of program evaluation as in Heckman and Hotz (1989) but could also be a key issue in our framework since both CO_2 emissions and per capita GDP can be plausibly depend on individual-specific trends in addition to the level effect, c_{i}. One main reason is that even countries belonging to similar geographical/economic groups tend to `specialize' with respect to innovation, energy and also policy. Innovation specialization (specific ways to innovate, e.g. patents or informal ways to adopt and protect; specific environmental innovations, e.g. climate change oriented, waste oriented, etc..) is due to both market characteristics and willingness to create comparative advantages. Policy specialization depend on the belief on policy-induced innovation effects, and on the ways country flexibly implement guidelines or Directives that set general targets (this is true for the EU scenario). Policy makers -- lobbyers strategic bargaining also matter (Aidt, 2010). Energy specialization depends largely on natural endowments, but also on innovation and policy actions (Johnstone at al., 2010; Dechezlepretre et al., 2011). Those are factors that we could appreciate in their specificity up to a point. We here start moving into detailed effects of time related factors, which may be more specifically defined and investigate in further analyses (e.g. the effect on EKC of a specific shock or policy). We therefore propose a nonparametric variant of the random growth model:

$$y_{it}=c_{i}+f(x_{it})+g_{i}(t)+\varepsilon_{it} \qquad (5)$$

which consists at generalising (2) making interacting the country's indicator variable with the nonparametric trend. This specification is often labelled as "factor-by-curve interaction" (Ruppert et al., 2003).

Introducing individual time trends really provides new insights (table 5, column "IFE_IT", Individual Fixed Effects and Individual Trends; fig. 7) from both statistical and economic viewpoints. It is interesting to note that, beyond the economic policy's insights, including individual time effects is also important from a statistical point of view. Indeed, both the Akaike/Bayesian Information Criterion - AIC and BIC - (table 5) strongly support such specification against the common time effects specification. Economic contents are also worth commenting on and enrich our previous outcomes.

First, it can be noticed that the CO_2-GDP relation become in all cases more linear (the edf is now 1, 1.28 and 3.87 for Umbrella, EU-North and EU-South, respectively. We recall that edf=1 means the relationship is linear) and clearly monotonic. This provides more evidence on the fallacy of EKC and on the biased evidence that homogeneous and parametric panel settings may present (Galeotti et al., 2009; Vollebergh et al., 2009).

Secondly, this new piece of investigation clearly shows, at least for Umbrella and EU-South, that the relation CO_2-time component is heterogeneous across countries. Indeed, for the Umbrella, such relation is overall roughly an inverted U for USA, Canada and Japan, while it is positive for the other countries (Australia, Norway and New Zealand).

`Innovation intensities' (especially patented innovation) that characterise the first set of countries and the energy structure of the economy, namely endowments of carbon intense sources, for the latter three, could well explain such within group differences that were hidden by the common time factor specification. A resource endowment `curse' materializes. Countries possessing larger stocks of (fossil fuel) resources (Australia in primis, especially CO_2 intense coal endowments) have comparatively less incentives to increase efficiency through innovation and to apply policies that reshape the energy structure towards coal-less sources. They are also less exposed to international energy shocks. Even along environmental performances that remain less positive with compared than northern EU, countries such as the US and Japan appear to have reacted differently and more efficiently to oil shocks of the 70's and 80's. This was an expected result.

For the EU-South, Austria, Ireland, Italy and Spain present an inverted U CO_2-time component relation, while Portugal and Greece show a positive and monotonic relationship. Thus, the monotonic relation CO_2-common time factor relation slighting out in the previous section appear specifically driven by the poorer set of countries confirming the `development' interpretation of EKC for such set of countries, that were situated still at mid 90's in the very low ranking in terms of GDP per capita. The comparison between two relatively anti-Kyoto groups of countries such as EU south and Umbrella shows with respect to individual time effects makes clear that the separate clustering is sound. The absence of EKC evidence both groups presented at the first stage of the analysis is explained by the fact that the time component does not `compensate' the monotonic positive income-carbon relationship. The net effect, contrary to EU north, remains unfavourable to absolute decoupling of those economies. In addition, we just noted that differences also exist between Umbrella and EU southern countries: while some of the first group were positively `shocked' by time events in the 70's-80 due to a relative scarcer abundance of fossil fuel resources, emissions of southern EU countries were in the end driven by a development oriented path. Where a structural time break is observed, it would be of interest to analyse its specific contents in future analyses.

For the EU-North, instead, the CO_2-time component relation is much more homogeneous across countries: it is clearly negative in all cases, even if some differences regarding the degree of nonlinearity appear. This indicates that the unobserved factors have negatively and primarily impacted the CO_2 emissions. It is true that this individual country analysis shows that within the EU most countries present a negative carbon-time component relationship. Most of the EU reacted to time events more effectively than other parts of the world. Those `reactions' are probably the major pre condition for the striking differences in (historically dependant) decoupling performances we observe today.

As already observed, for northern EU countries time effects in the end matter much more than and actually outweigh income-related ones. The evidence attached to them is consistent across those countries and further make robust what we highlighted when commenting on `common time' trend results. The factors explaining this evidence are largely linked to the way EU northern countries reacted to oil shocks, mainly through energy saving and innovation oriented investments. Such reactions were then later also characterise by a more effective adoption of environmental policy, including a relatively larger use of market based instruments as carbon taxes (Andersen and Ekins, 2009, and the 2006 special issue in Energy Policy), which could eventually be introduced in the future in North America and Oceania as well (Metcalfe, 2008). The EU-North countries in fact present negative, robust and consistent CO_2-unobserved time factors relation. This evidence is coherent with recent evidence on the average EU performance (+1,5% GHG emissions of CO_2 with respect to 1990 Kyoto baseline in 2008), which shows that it is driven by absolute delinking reached in countries such as Germany, UK, Sweden, Finland, France and by the worse performance of Spain, Italy, Denmark, Austria among others (Borghesi, 2010, EEA, 2008). Those countries have also supported more than others the design and implementation of an ETS (Convery, 2009) in the EU.

Indeed, it is worth noting that where the relation CO_2-time is of inverted U type, the turning point is approximately located in the 70s. This point further suggests the primary role that was exerted by oil shocks, and surely by the following reactions and adaptations to (expected) increasing oil and CO_2 prices.

As a final step to the analysis focusing on `individual country time effects', we can set both income and time factors as heterogeneous factors across units. A more general specification can in fact be obtained by considering both individual time effects and individual income effects:

(6) $$y_{it}=f_{i}(x_{it})+g_{i}(t)+c_{i}+\varepsilon_{it}$$

The results (table 5, column "IFE_IT_IG", Individual Fixed Effects, Individual Time and Individual GDP effect; and figure 8) are fully coherent with what presented so far, but still deserve some comments. In fact, on the side of statistical performances (AIC, BIC) it does improve very marginally upon the random growth -- homogeneous income effect specification. Nevertheless, on the side of economic significance, we highlight that the only two countries showing an inverted U EKC for the income-carbon relationship are Sweden and Finland. Those are countries at the top of GDP and Human development indexes, with a relatively low share of industry in the economy (and very environmentally efficient specialized industries). All factors that had well been precursors of their environmental policy attention since the late 80's. Thus, as expected Scandinavia emerges in the leading positions of the EKC performance, though we already noted how the energy sources used to fuel the economy penalizes Denmark and Norway to some extent. This is a clear example of how income-carbon (and time-carbon) dynamics present highly idiosyncratic and heterogeneous contents that deserve specific attention and can differentiate potentially similar countries.

Conclusions

This paper extends previous and recent analyses on Carbon Kuznets curves in three complementary directions. First we adopt a classification of countries mainly based on their `carbon abatement' orientation. This allow us to provide many new insights both in terms of economic policy and methodological, especially with respect to the issue of the heterogeneity bias associated to the estimation of large samples of heterogeneous countries. From a methodological viewpoint we indeed show that when estimating the empirical specification on the full sample of countries we erroneously found an inverted U CO_2-GDP relation even adopting a random-coefficient estimator, clearly showing how important can be to estimate the CKC on samples of quite homogeneous countries.

Secondly, we estimate the model with common nonparametric trend in order to avoid the omitted time related factors bias. We adopt a GAM framework because it allow us to focus our attention also on the CO_2-unobserved common factors relation rather than only looking at the "net" CO_2-GDP relation. Time related factors, whose content is mainly driven by innovation and policy elements, appear to matter much more than income driven factors in explaining EKC shapes. For the cases in which an EKC is robustly found- Northern EU-, it is the role of time factors that matter. Income-carbon relationship is heterogeneous across groups of countries regarding the elasticity, but is all fully positive and linear in the end. If on the one hand income effects appear to matter relatively more for Umbrella and Southern EU countries, time effects dominate and drive long run emission-income relationship for northern EU countries. Sweden and Finland only appear to present inverted U income-carbon relationship in the end.

Finally, when we include individual time trends by adopting a nonparametric extension of the random growth model, an additional insight and most original result is emerging. From both a statistical and economic point of view this model dominates the `common time trend' specification. It gives country based insights on what is behind the "common unobservable time effect". We first note that the more we detail the time related part of the analysis, the more the GDP-carbon link becomes linear. Secondly, while sticking to a sound grouping of countries in terms of their structural features, it shows that heterogeneity regarding non

GDP time related factors well explain some differences of performances even within groups. As main example, Umbrella group seem to have reacted differently to oil shocks. This evidence is highlighted in the individual time effects analyses wherein US and Japan present negative effects of time factors on carbon dynamics, while the common time trend for Umbrella group was positively affecting emissions.

Overall, the countries under study differ more on their CO_2-time relation than on the CO_2-GDP relation which is in almost all cases monotonic positive. In the end, we claim that the omitted time related factors bias is found to be empirically much more important than the heterogeneity bias associated to the estimation of common income effects. One main message of the paper is that the EKC relationship is explained to a large extent by time related factors, whose specific policy, energy and innovation contents deserve careful investigation in the future. Their heterogeneity is more important for explaining the EKC shape. This both confirms the fallacy of the simple EKC adage, and moreover highlights the `structural change' nature of income-environment relationships, that could be in the end largely and mostly affected by time related events, including shock events. This is scope for further research that should focus on the explanation of the specific contents. One direction is to test whether and which energy/policy shocks were significant and caused a structural break in the EKC dynamics.

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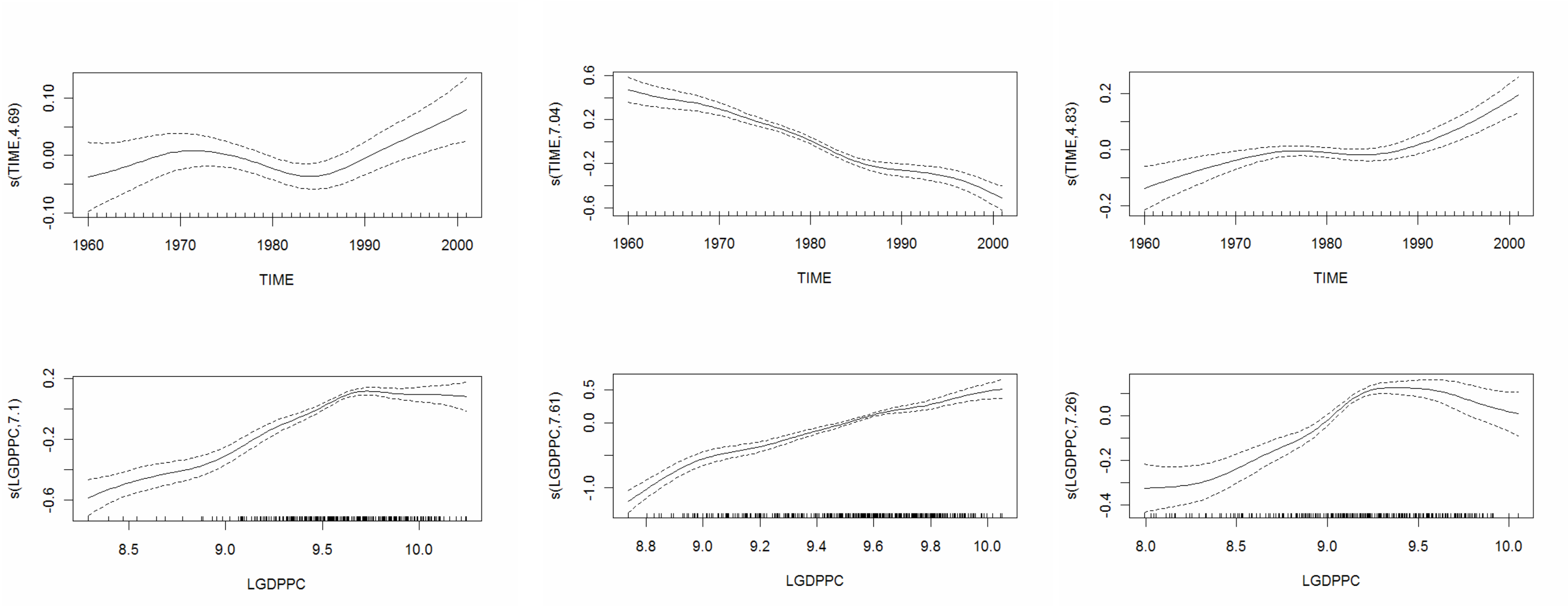
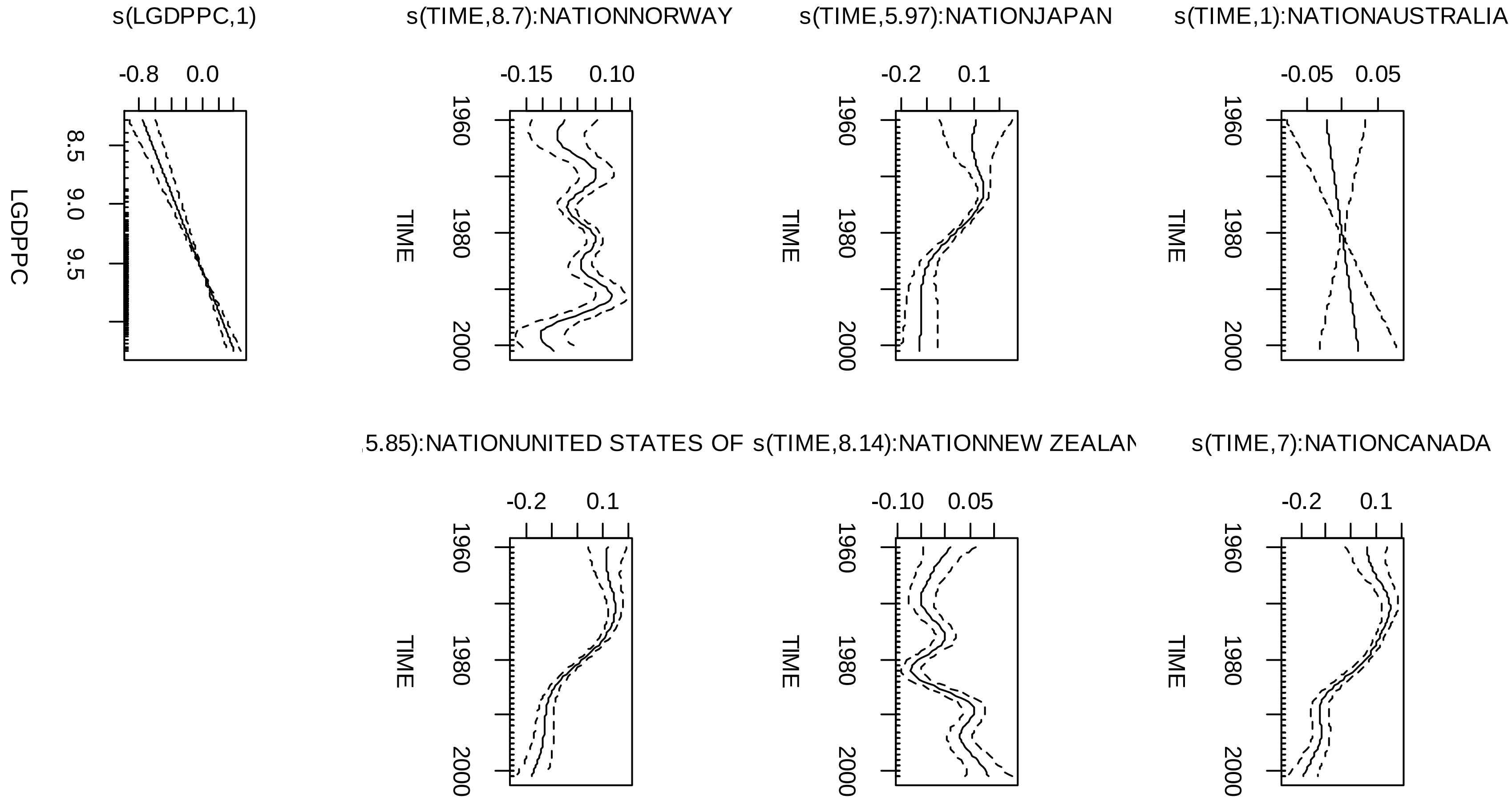


Notes. s(LGDPPC, edf) indicates the estimated smooth function (and its 95% confidence interval) of log (GDP per capita) ($f(x_{it})$ in eq. 2) and edf represents the estimated degrees of freedom. s(TIME, edf) indicates the estimated smooth function (and its 95% confidence interval) of time ($g(t)$ in eq. 2) and edf represents the estimated degrees of freedom.

Figure 6 - GAM with individual fixed effects and nonparametric common trend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0.0
8.5
9.0
9.5
LGDPPC
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-0.15
0.10
s(TIME,5.97):NATIONJAPAN
-0.2
0.1
s(TIME,1):NATIONAUSTRALIA
-0.05
0.05
5.85):NATIONUNITED STATES OF
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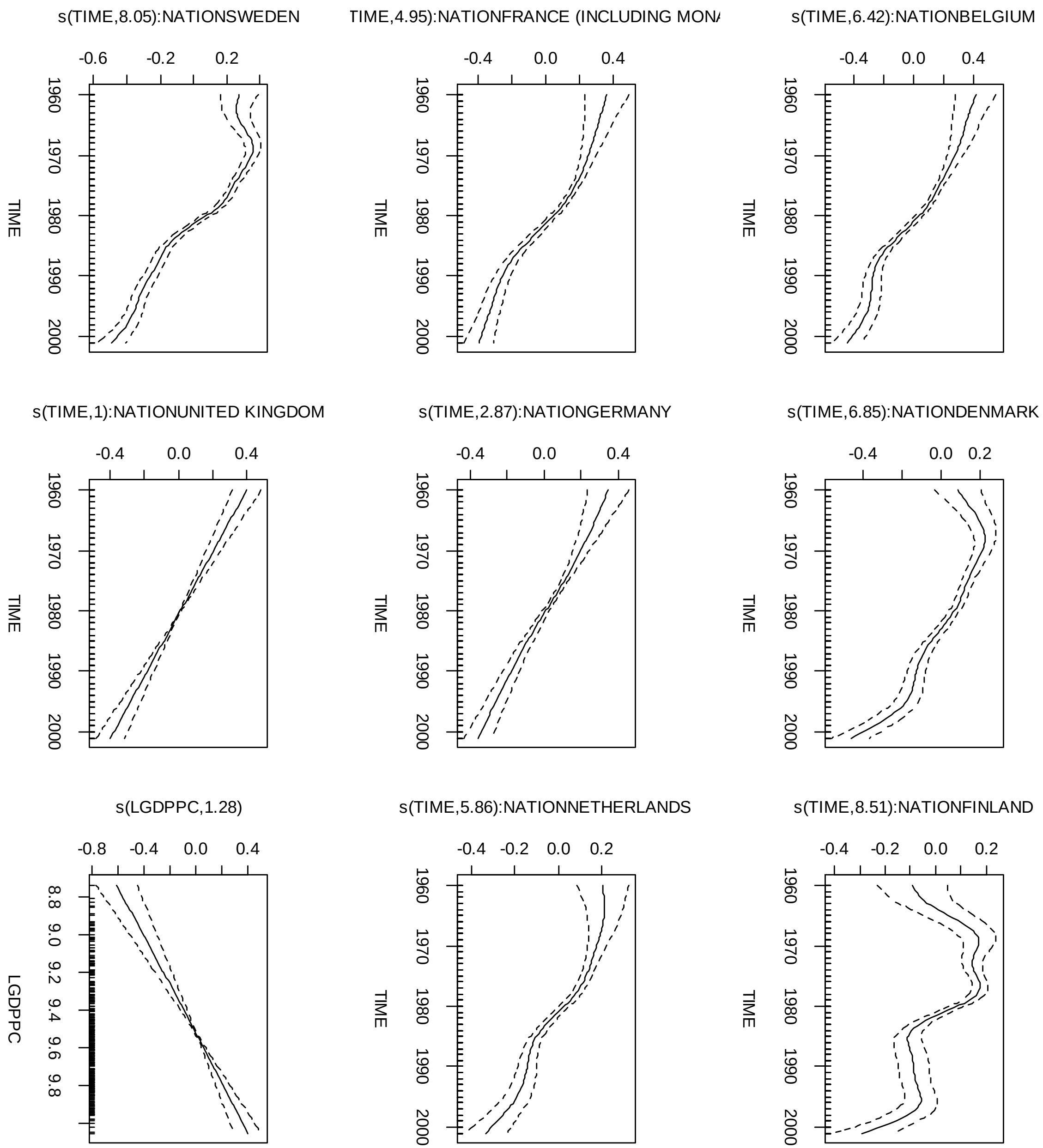
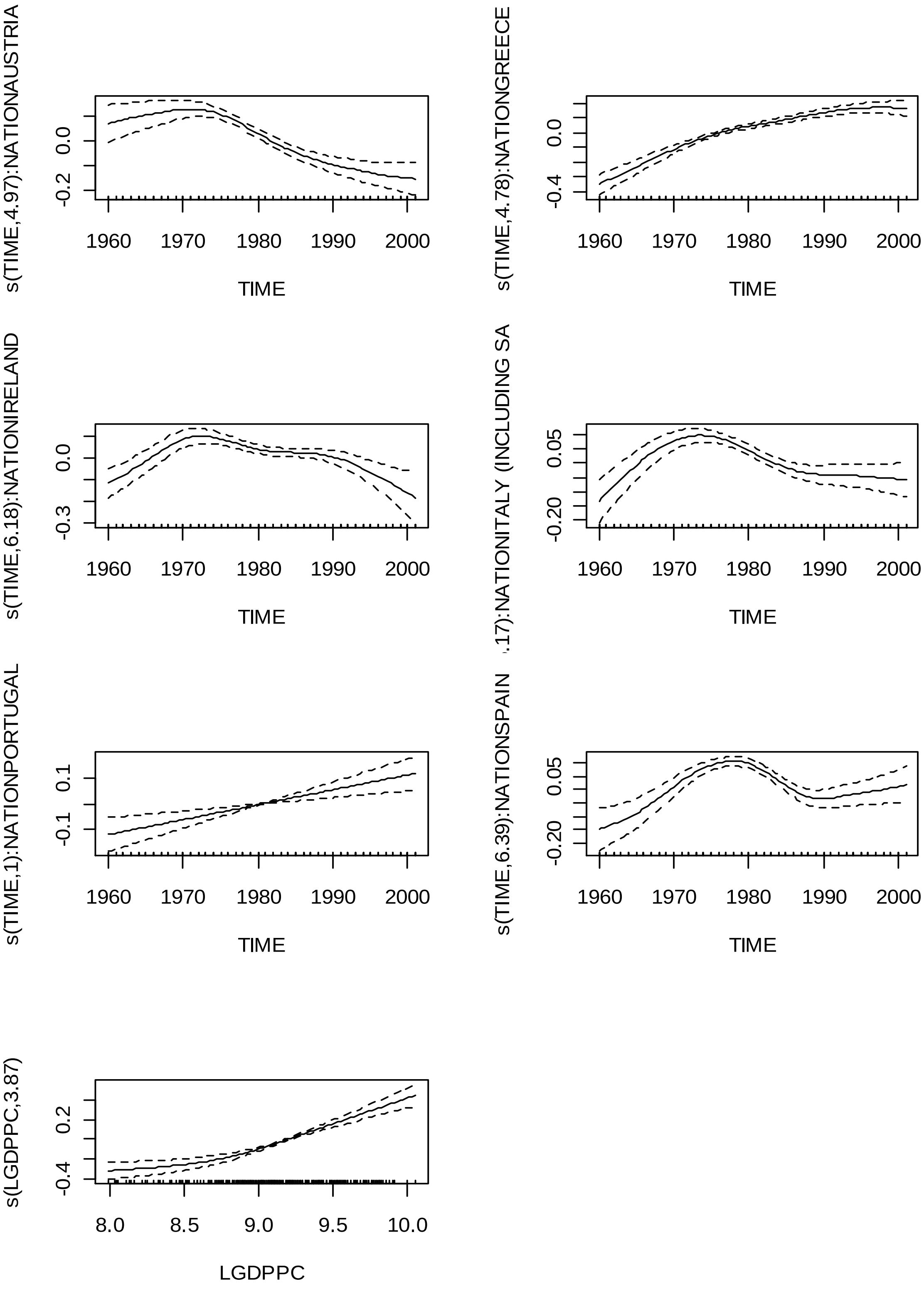
-0.10
0.05
s(TIME,7):NATIONCANADA
TIME
1960
1980
2000


s(TIME,8.05):NATIONSWEDEN
TIME,4.95):NATIONFRANCE (INCLUDING MON/
s(TIME,6.42):NATIONBELGIUM
s(TIME,1):NATIONUNITED KINGDOM
s(TIME,2.87):NATIONGERMANY
s(TIME,6.85):NATIONDENMARK
s(LGDPPC,1.28)
s(TIME,5.86):NATIONNETHERLANDS
s(TIME,8.51):NATIONFINLAND
TIME
LGDPPC

EU NORTH

EU SOUTH



Notes. s(LGDPPC, edf) indicates the estimated smooth function (and its 95% confidence interval) of log (GDP per capita) ($f(x_{it})$ in eq. 3) and edf represents the estimated degrees of freedom.

s(TIME, edf)NATION "NAME OF THE COUNTRY" indicates the estimated smooth function (and its 95% confidence interval) of the "factor-by-curve interaction" (interaction between the common trend and the country's indicator variable, $g_i(t)$ in eq. 3) and edf represents the estimated degrees of freedom.

Figure 7 - GAM with individual fixed effects and nonparametric individual trend

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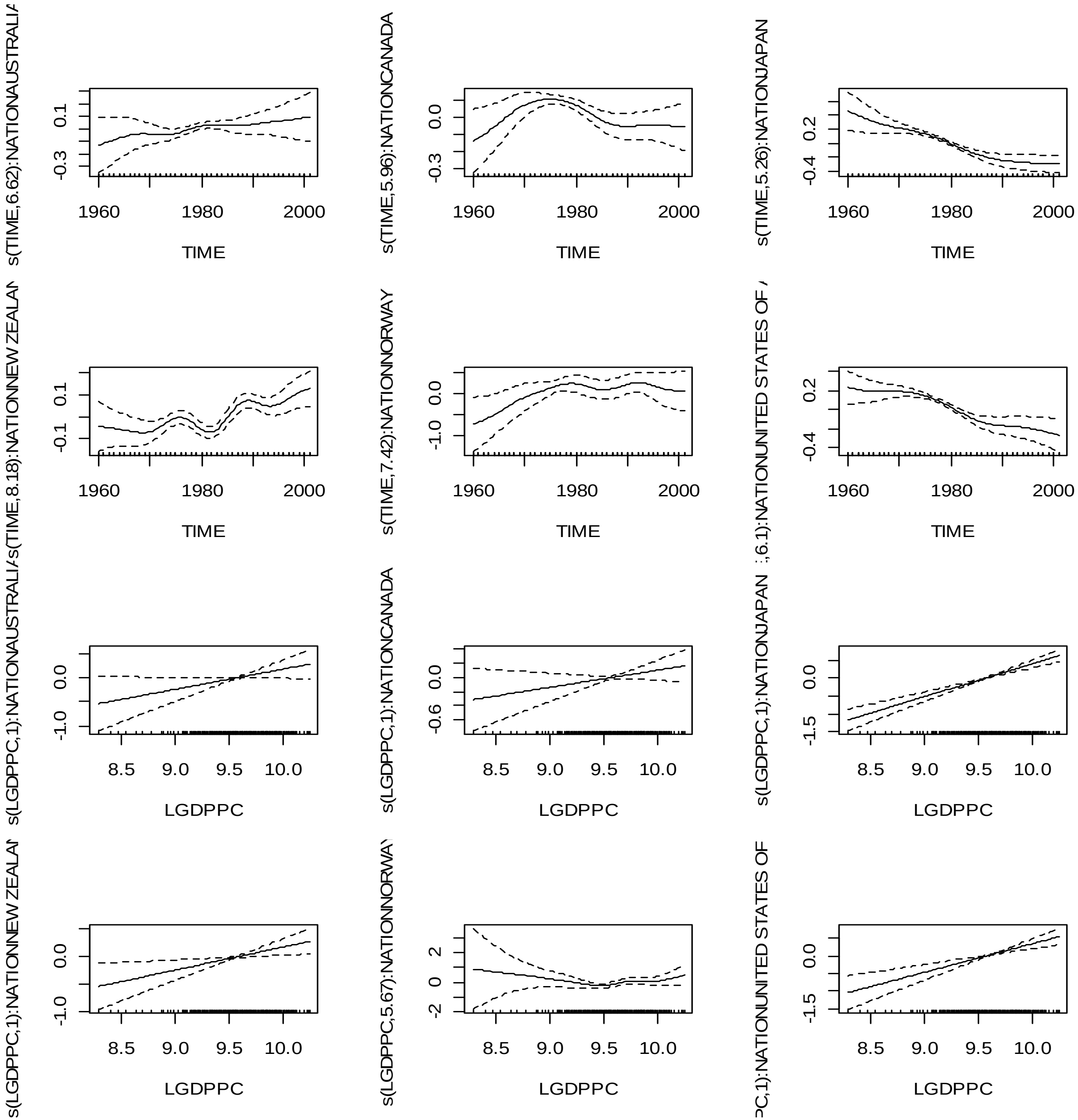
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TIME
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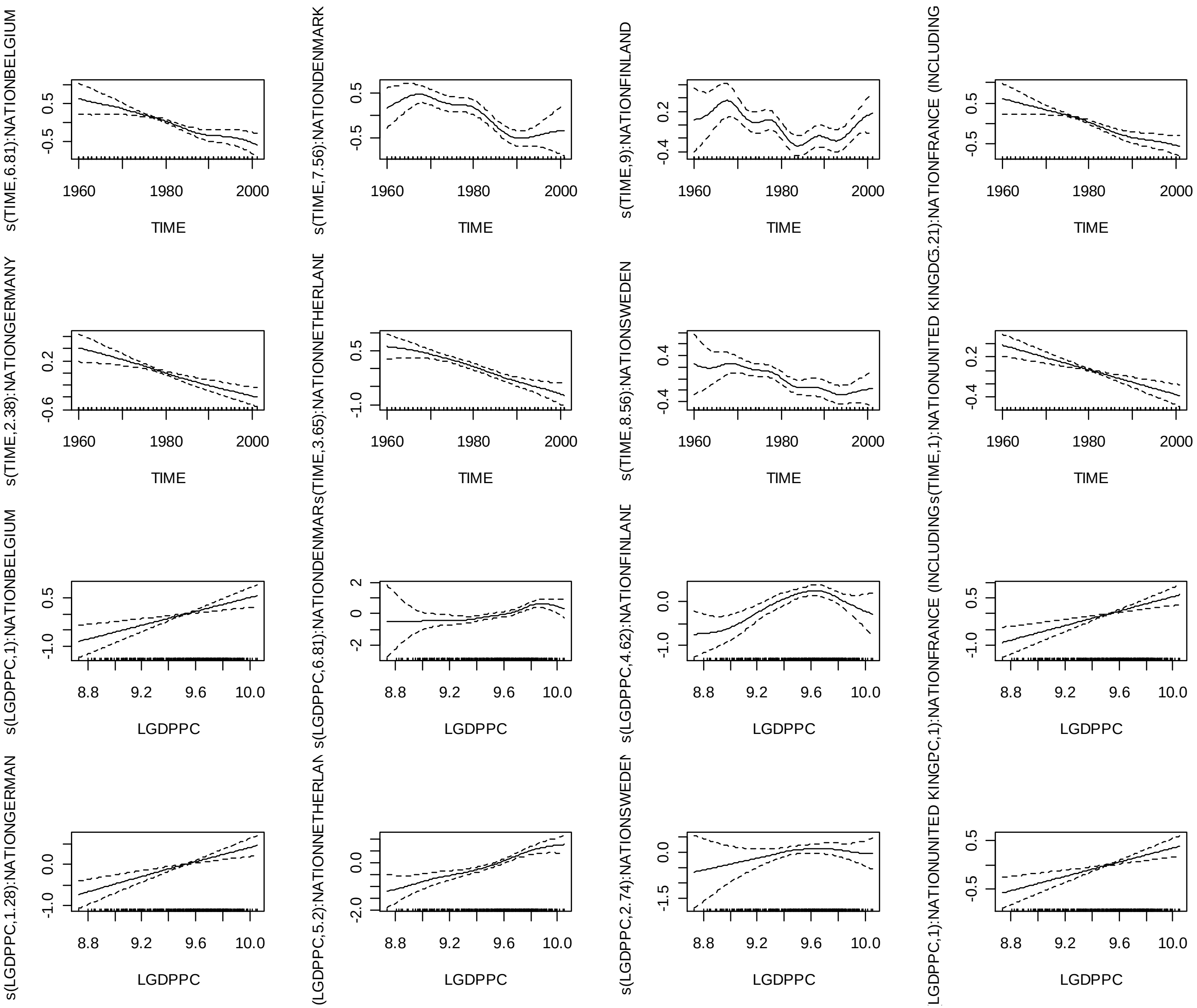
LGDPPC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s(TIME,9):NATIONFINLAND
s(TIME,5.21):NATIONFRANCE (INCLUDING
s(TIME,2.38):NATIONGERMANY
s(TIME,3.65):NATIONNETHERLANI
s(TIME,8.56):NATIONSWEDEN
s(TIME,1):NATIONUNITED KINGDO
TIME
1960
1980
2000
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s(LGDPPC,6.81):NATIONDENMAR
s(LGDPPC,4.62):NATIONFINLANI
s(LGDPPC,1):NATIONFRANCE (INCLUDING
s(LGDPPC,1.28):NATIONGERMAN
(LGDPPC,5.2):NATIONNETHERLAN
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LGDPPC
8.8
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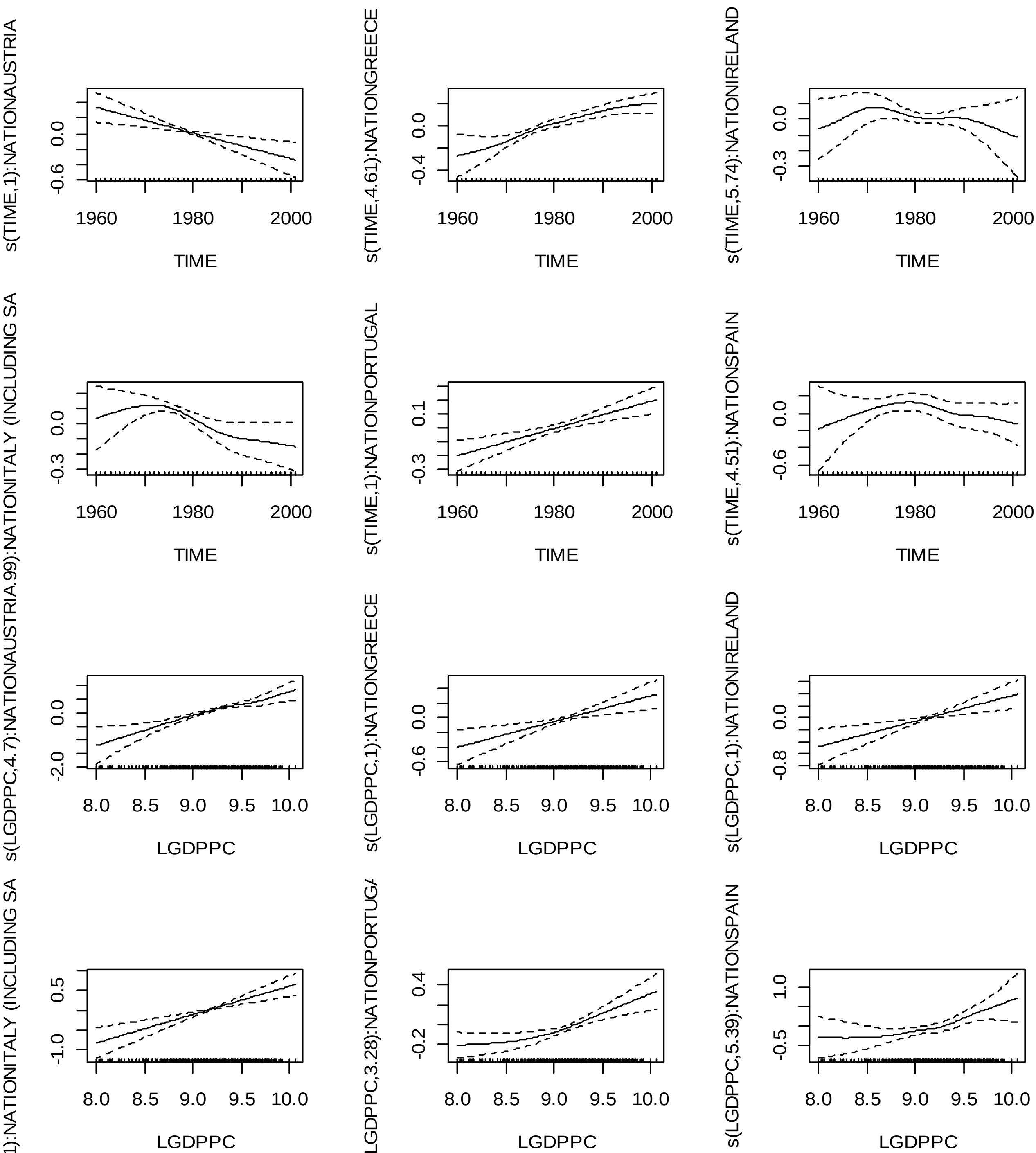
EU SOUTH



Notes. s(LGDPPC, edf) NATION "NAME OF THE COUNTRY" indicates the estimated smooth function (and its 95% confidence interval) of the "factor-by-curve interaction" (interaction between log(GDP per capita) and and the country's indicator variable, $f_i(x_{it})$ in eq. 4) and edf represents the estimated degrees of freedom.

s(TIME, edf)NATION "NAME OF THE COUNTRY" indicates the estimated smooth function (and its 95% confidence interval) of the "factor-by-curve interaction" (interaction between the common trend and the country's indicator variable, $g_i(t)$ in eq. 4) and edf represents the estimated degrees of freedom.

Figure 8 - GAM with individual fixed effects, nonparametric individual trend, and individual GDP effect