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Carbon Kuznets curves in the climate change political economy arena

New evidence comparing various panel estimators

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Abstract

The paper analyses the extent of structural differences among climate change leading 'actors' - Northern EU members, southern EU countries and the so called 'Umbrella group' - with regard to intrinsic income-environment relationships and their climate change policy perspectives. Homogeneous estimators and heterogeneous estimators allowing individual slopes are employed by emphasising both cross-section correlation and adjustment dynamics. We find that the group of countries that is less in favour of stringent climate policy have yet to experience a Kuznets curve, though they show relative delinking in the carbon-income relationship. Northern EU countries tend to show bell shapes. Heterogeneous based panel models seem to perform relatively better at capturing the dynamic link between income and environment. Results are relevant from both an economic and a methodological point of view, and provide food for thought in terms of post Kyoto negotiations.

Keywords: Carbon Kuznets Curve, panel cointegration, heterogeneous panels, cross-section correlation, Kyoto framework, Bayesian models

JEL classification: C23, Q53

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0. Introduction

Indicators of decoupling, that is improvements in environmental/resource indicators with respect to economic indicators, are increasingly being used to evaluate progress in the use of natural and environmental resources (OECD, 2002; EEA, 2003). Stylised facts have been proposed on the relationship between pollution and economic growth, which became know as the Environmental Kuznets Curve (EKC) hypothesis on the relationships between economic growth and the environment 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) a large body of theoretical studies have investigated and tested hypotheses within the EKC framework.

Applied EKC investigations mainly focus on emissions into the air, although evidence for other types of emissions and pollutants, such as waste, has been emerging since 2000. In this paper we focus on CO_2 emissions which have been recognised as a major source of environmental pollution (Schmalensee *et al.*, 1998), and offer the most robust data for applying advanced econometric techniques.

Empirical evidence in support of an EKC dynamics, or a delinking between emissions and income growth, is limited and not very robust in the case of CO_2 and local air and water pollutants (Cole *et al.*, 1997; Bruvoll and Medin, 2003), which often show a clear absolute delinking. Decoupling between income growth and CO_2 emissions is not (yet) apparent for many important world economies, and where it is observed, it is relative rather than absolute as usually assumed by the EKC hypothesis.

This paper aims to contribute to the development of EKC research in two main directions. First, we focus on a policy relevant scenario, in which pro-Kyoto countries and the Umbrella Group, respectively led by the EU and the US, negotiate over climate change strategies, a scenario that is becoming very important in the post-Kyoto phase. Although the picture we present refers to the ten years from 1998, and we are aware that the political arena is changing (e.g. democratic president elect in the US), our aim is to provide food for thought for political negotiators in the context of the post Kyoto era, by examining the extent to which the structural differences of different 'groups' of countries might explain their different policy perspectives and economic capabilities to tackle the climate change issue.

Second, we use modern econometric panel approaches capable of providing useful complementary information. We employ homogeneous estimators, such as the fixed effects model (FEM) and more recent estimators derived from panel cointegration analysis (PCA) (Kao and Chiang, 2000; Phillips and Moon, 1999) as well as heterogeneous estimators which allow individual slopes to be derived from sampling (Pesaran and Smith, 1995) or Bayesian approaches (Hsiao *et al.* 1999). It is difficult *a* priori to decide between homogeneous and heterogeneous panel estimators. On the one hand, the increasing time dimension means that the slope homogeneity implicit in the use of a pooled estimator is questionable. On the other hand, most researchers agree about the use of homogeneous estimators

since the efficiency gains from pooling often overcome their costs (Baltagi *et al.* 2000, 2002, 2004). Some researchers have suggested using "intermediate" estimators as Bayesian shrinkage estimators (Maddala *et al.* 1997) - to shrink the individual estimates towards the pooled estimates or the Pooled Mean Group (PMG) estimator (Pesaran *et al.,* 1999), allowing intercepts, short-run coefficients and error variances to differ freely across cross-sections, while long-run coefficients are held constant.
Since the independence assumption implicit in such approaches can be questionable, also some estimators allowing for cross sectional correlation are employed, as the Driscoll-Kraay (1998) non parametric estimator which can viewed as a variant of the Newey and West (1987) time series covariance matrix estimator or the Dynamic Seemingly Unrelated Regressions which take into account of cross sectional correlation in a panel co-integrated framework (Mark et al., 2004).

Empirical evidence based on this methodology provides useful information for: (i) the current scenario, in which the US is slowly coming to recognise the need to tackle climate change, but favours flexible policy instruments, and the EU is leading Kyoto implementation (Kruger and Pizer, 2004; see also the update developed in *Resources for the Future*); and (ii) the post Kyoto negotiation round, which should set the framework for the new climate change policy scenario. The Umbrella group has supported a radical interpretation of the EKC: economic growth that drives technological improvements, is what is needed to achieve a sustainable path. The EU supports the hypothesis that policy making should target the climate change 'business as usual' (BAU - no policy) by favouring the emergence of an EKC,[1] and eventually the turning point (TP) level of the carbon Kuznets curve.

We aim to shed light on the effective differences in the income-environment relationships across different groups of countries participating in the reshaping of climate change actions - now and in the near future. We test the divergences in EKC shapes (CO_2 to gross domestic product (GDP) elasticities, TP, quadratic or cubic forms of the relationship) across groups. A lower elasticity and/or EKC evidence for a group could explain stronger support for Kyoto, deriving from better historical environmental performance and favourable structural conditions. It is these factors that most likely explain the stronger support for policy implementation, which, increasingly has been studied as an endogenous element (Cole *et al.*, 2006; Cagatay and Mihci, 2006), driven by income, social preferences and idiosyncratic national/regional factors.

Nevertheless, this is the 'average picture'; reasoning at the margins, a lower positive elasticity or a negative elasticity (achieved TP) could be associated more with higher marginal abatement costs, than reduced incentives for further efforts - at least at the national level. Our analysis then is an implicit test of whether average or marginal considerations prevail in national or pressure group policy strategies. Average-driven considerations show that policy based reasoning prevails over economic (marginal) reasoning, and that policy actions are dependent on income and other idiosyncratic factors. For

[1] The occurrence of a TP does not assure 'sustainability' (Stern, 2004).

example, if the EU should emerge as a group associated with lower carbon-income elasticity, its stronger support for Kyoto might be motivated less by pure economics as marginal achievements are likely to be more costly with respect to achievements in the US. Flexible instruments and overseas abatement, two pillars of the Umbrella group strategy, should be supported instead. The northern EU countries' emphasis on climate change might not be wholly irrational however, if we consider that policies are endogenous and driven by multifaceted factors, including achievement of competitive advantage in national green industries and green technologies, which could be spurred by more stringent environmental actions. Strategic behaviour might be rooted in economics if we consider that being a first mover might bring future benefits in terms of easier achievement of (stricter) post Kyoto targets and of innovation/technology related rents, partially spurred, as demonstrated in the literature, (Porter and van der Linde, 1995; Jaffe *et al.*, 1995; Brunnermeier and Cohen, 2003) by policy. Alternatively, in case of not significantly different strategies among groups, policy divergences may be judged as being merely tactical rather than being rooted in economic rationales. They may be viewed as actions within the strategic game played by countries at international level related to the production of a global (impure) public good 'CO_2 abatement' (Kotchen, 2005).

We argue that compared to studies based on OECD country or world wide datasets,[2] a focus on specific regions, and groups of homogenous countries, would provide a sounder basis for economic and policy reasoning.[3] Economic and statistical aspects should be considered jointly in the environmental economic/policy arena.

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

1. The EKC state of the art

1.2 Theoretical underpinnings: recent developments

The EKC literature has moved from basic conceptual intuitions and stylised/empirical facts, which traditionally fed EKC analysis, to the search for theoretical foundations for EKC empirics and inclusion of the EKC hypothesis in formalised economic models. Such models generally try to explain

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[2] Most works included in our overview focus on world wide datasets (e.g. Agras and Chapman, 1999; Azomahou et al., 2006), which are often based on the data available, and data on the OECD countries as a set (e.g. Cole, 2005; Galeotti et al., 2006; Martinez-Zarzoso and Bencochea-Morancho, 2004). However, within the OECD group there is great heterogeneity in terms of the stage of development of economies, and taking these countries as a group is not relevant in our eyes.

[3] Here we focus on 'developed' areas e.g. western EU and the developed OECD countries. Some EKC analyses have emerged for countries such as India and China (Auffammher and Carson, 2008; Brajer et al., 2008; Managi and Ranjan Jena, 2008; Song et al., 2008), but there is a lack of evidence on transition eastern EU areas.

EKC dynamics by technological, externality type, preference based and policy factors. Although in this study our work is empirical, we provide a short survey of the literature in order to establish the boundaries of current economic reasoning on EKC. An extensive overview of the main theoretical issues can be found in Copeland and Taylor (2004).

Andreoni-Levinson (2001) provide a seminal work that uses a Cobb Douglas technology framework, and suggests that EKC dynamics may be quite simply technologically micro founded, and might depend on increasing returns to scale,[4] rather than being related strictly to growth and externality issues. Variable returns to scale (VRS) along development paths (increasing then decreasing) may lead, for example, to non-linear (two humped) EKC trajectories. Other works provide technology based explanations for the EKC path. Jaeger and van Kolpin (2008) show that the sufficient conditions for EKC are identified by a range of models and parameters in production functions settings, including homothetic, constant returns to scale (CRS), CES functions. Growth in income and in population can produce socially efficient inverted U shaped patterns. Pasche (2002) addresses theoretically the role of technological change in goods and production as a pre-requisite for an EKC sustainable evolutionary economic growth. Smulders and Bretscgher (2000) provides an analytical foundation for the claim that the rise and fall in pollution may be linked to policy-induced technological shifts. Kelly (2003) focuses on environment related technology showing that the EKC shape depends on the dynamic interplay between marginal costs and the benefits of abatement.

At the macroeconomic level, Brock and Taylor (2004) claim for the integration of the EKC framework within the Solow model of economic growth; this amended model generates an EKC relationship between flow of pollution emission and income per capita, and stock of environmental quality and income per capita, with the resulting EKC either an inverted U shape or strictly declining. A similar dynamic theoretical analysis based on endogenous growth model is provided by Dinda (2005), who focuses on the dynamic allocation of capital between two sectors (production and abatement), in order to see whether EKC are coherent with socially optimal paths. And Chimeli and Braden (2005, 2008) integrate EKC in a total factor productivity (TFP) model, and looks at the role of capital scarcity theory. Khanna and Plassmann (2007) respond, maintaining that a general condition exists, not dependent on either differences in TFP or decreasing returns to abatement. The income-pollution link is instead driven by contemporaneous changes in the marginal rate of substitution between environmental quality and consumption on the demand side, and the marginal rate of transformation between those goods on the supply side.

Social and market discount rates, highly heterogeneous across developed and developing countries, could play an important role in explaining the observed income-pollution pattern. Low levels of income

[4] Increasing returns to scale also emerge as a key factor in Egli and Steger (2007) who propose a macroeconomic model including social preferences and technological development. They offer potential theoretical explanations for N shaped curves.

involve high discount rate values, which are obstacles to the adoption of a pollution abatement policy. Dynamic social preferences and growth issues related to EKC are investigated in Chavas (2004).

Analyses based on dynamic models are attracting increasing attention from scholars interested in assessing EKC roots. Anderson and Cavendish (2001) exploit simulation analysis by including policy analysis in their study. Prieur (2007) measures the repercussions of irreversibility (of the pollution) on the relationship between growth and the environment. Since the seminal work by Arrow and Fisher (1974), the role of irreversibility and uncertainty of development has been crucial to explain sustainable economic growth. Prieur notes that economic growth may be accompanied by the accumulation of ecological debt, but, due to the irreversible nature of some pollution, the debt may be such that, once the economy engages in maintenance, the effort is not sufficient to avoid the irrevocable degradation of the environment. Dynamic scenarios intrinsically deal with the accumulation of (welfare enhancing or decreasing) assets. Some authors have suggested that for stock pollution externalities the pollution-income relationship difficulty becomes an EKC shaped curve, with pollution stocks monotonically rising with income (Lieb, 2004). Flow-stock differences related to externalities thus interact with technology and capital accumulation. Ranjan and Shortle (2007) links stock effects and irreversibility issues, claiming that points of no return can occur if hysteresis effects are associated with pollution accumulation. It is possible to revert back, and to drive a path to more sustainable levels only if certain threshold combinations of capital and degradation accumulation are not crossed.

Notwithstanding the increasing relevance of the theoretical studies on EKC,[5] it is quantitative analysis that dominates. However, we believe, there is room for improvements at the margins.

1.2 Towards new applied directions

Recent works have highlighted, on the basis of newly updated data and new techniques, that there is some evidence supporting EKC shapes for CO_2 , even differentiating by geographical areas and by estimation techniques (Martinez-Zarzoso and Morancho, 2004; Vollebergh *et al.*, 2005; Cole, 2003; Galeotti *et al.*, 2006). Although the evidence is patchy, that is, heterogeneous across studies (which use different data with respect to time span and countries), there is some EKC evidence for CO_2 emerging for the OECD countries. This is leading to greater optimism, counterbalancing the rather pessimistic views of no TP and a fragile EKC hypothesis (Harbaugh *et al.*, 2002; Millimet, List and Stengos, 2003).[6]

[5] There are numerous theoretical underpinnings to the Kuznets framework. What would seem to be an intrinsic weakness of this analysis, i.e. the lack of defined hypotheses, in reality is its value: the flexibility from facilitating diverse research directions and the testing of multiple explicit and implicit assumptions.

[6] Wagner (2006) and Muller Furstenberger and Wagner (2007), highlight various drawbacks from theoretical and empirical points of view, and question EKC evidence, finding no inverted U shape for CO_2 in their analyses of a balanced panel dataset of 107 countries over 1986-1990. Chimeli (2007) offers a theoretical explanation for the failure to find EKC paths when using (cross country) panel datasets, and offers some guidance for future empirical work mainly on time series or panel data, in country-specific settings. Galeotti et al. (2006) are rather sceptical about EKC and test the robustness of the EKC hypothesis, analysing CO_2 series. They take as starting point the mixed evidence on EKC, showing first that the evidence seems not to depend on the source of the data (IEA or other), and that reasonable TP emerge for OECD

Thus, the evidence is far from conclusive and continues to grow based on ongoing research aimed mainly at verifying the robustness of results across different models. We would agree, therefore, that a 'best' model for analysing EKC does not exist. In addition, at a certain level of advanced analysis, statistical 'fit' comparisons across models are harder to implement. A consolidated assessment of results is still underway; critical points and heterogeneity of outcomes across models are currently being tackled. Finally, there is often a lack of policy relevance given the nature of data and the objectives of analyses. Here, we aim to check robustness across different models, in order to provide results that will inform policy. We briefly critique the more recent analyses, focusing on work that deals with dynamics and structural heterogeneity in panels.

There is a series of papers providing empirical evidence, that exploit flexible panel parametric specifications and non-parametric methods. Martinez-Zarzoso and Bengochea-Morancho (2004) analyse CO_2 data for the period 1975-1998, for 22 OECD countries, by applying the PMG estimator, which allows for slope heterogeneity in the short run, imposing restrictions only in the long run; it also allows for the presence of dynamics. The evidence favours an N shape for the majority of OECD countries and an EKC inverted U shape for the less developed countries. The range of implied TPs is nevertheless too wide to lead to solid conclusions. Within the studies focusing on OECD countries as a group, Cole (2005) applies the heterogeneous Swamy random coefficients estimator and concludes that the income-pollution relationship varies widely across countries. This suggests that the assumption of constants coefficients across countries in the traditional fixed-effects specification is inappropriate. More fundamentally, it suggests that there is no income-pollution relationship that is common to all countries and hence the very existence of a general EKC is questionable.

Recent developments in the literature test the robustness of the EKC hypothesis using either flexible parametric specifications or partially or fully non parametric models, or by looking at the cointegration properties of CO_2 time series; they have produced mixed results. The main criticisms are focused on the plausibility of a standard 'homogenous' panel when dealing with cross country analysis, where there may be different income-CO_2 relationships.

Dijkgraaf and Vollebergh (2005) and Vollebergh *et al.* (2005) allow for both heterogeneity across countries and flexible (non-parametric) functional form, and show that traditional panel models with country specific or country and time effects may present TPs within the observed income ranges; nevertheless, the null hypothesis of slope homogeneity is strongly rejected by the data. Dijkgraaf and Vollebergh analyse sample of 24 OECD countries for 1960-1997. The most striking result is that time

countries (taken as a whole). Deaton and Norman (2006) use within-country data and non-parametric techniques; for smoke and SOx they find no robust evidence in support of the EKC theoretical framework.

series analysis provides a different picture from heterogeneous panel estimations. Only five out of 13 countries that show evidence of EKC dynamics present coherent results in the two frameworks.[7] Vollebergh *et al.* (2005 explore various parametrical and non parametric specifications for a CO_2 dataset of OECD countries and find that EKC shapes are quite sensitive to the degree of heterogeneity in the panel estimations. Parametric models generate EKC shapes with quite low TPS, while the evidence is less robust from semi-parametric estimations. The non-parametric setting demonstrates the necessity to incorporate heterogeneity, which leads to the exploration of single country specific time series, and suggests caution in interpreting panel based EKC outcomes if they do not in some way address the heterogeneity issue. The existence of an EKC curve in cross country international frameworks such as OECD country based analyses, may depend on the balance between high income countries showing an inverted U shape dynamics and high income countries that present a still positive elasticity of emissions with respect to income.

The role of semi-parametric and non-parametric EKC estimations is tackled by Azoumahou *et al.* (2006), who use CO_2 data for 1960-1996 for 100 countries, applying non-parametric and parametric specifications to compare models. They find that EKC shapes arise when a parametric panel model is used (positive signs for the linear and squared terms, and negative sign for the cubic term), but that a monotonic relationship emerges in both the non-parametric settings and the first difference regressions, as in the semi parametric analysis of Bertinelli and Strobl (2005).[8]

On the basis of recent theoretical and empirical developments, we maintain that EKC analysis, despite its weaknesses, is a useful tool for investigating income-environment relationships. More knowledge about these links would be useful for assessing ex post different (across countries) policy and technological dynamics, and providing insights for the setting of future strategies and policies. Since the weaknesses are largely related to data quality, data quantity, and poor econometric analysis, these issues should be the focus of future work. There are various trade offs: cross country datasets typically offer large and long datasets, but few covariates; regional data are richer in explanatory factors but smaller in size. Over time as more information becomes available, researchers could attempt to reconcile the quality and quantity of data. In light of recent empirical developments, we would argue that, with the increased time dimension of the panel data sets, the choice of a more heterogeneous

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

[8] On sulphur emissions Halkos (2003) exploits a large panel dataset comprising 31 years (1960-1990) and 73 OECD and non-OECD countries, applying random coefficients and general method of moment (GMM). The results are in complete contrast to those obtained using the more usual fixed and random effects models. Taskin and Zaim (2000) used non parametric production frontier techniques, establishing an EKC relationship by kernel estimation methodology.

estimator may be preferable from an econometric point of view (Pesaran and Smith, 1995; Pesaran *et al.*, 1999; Hsiao *et al.*, 1999)[9].

3. Model specification, estimation and data

3.1 Specification

Following the EKC and IPAT related literatures, and the main EKC oriented studies (e.g. Cole 2005; Stern, 2004; Azomauh *et al.*, 2006; Harbaugh *et al.*, 2002), the per capita CO_2 emissions from a country i in period t is modelled as a function of per capita GDP, with both variables expressed in logarithms:

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

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

2. $y_{it} = \alpha_i + \theta_1 x_{it} + \theta_2 x_{it}^2 + \varepsilon_{it}$

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

where y_{it} is the logarithm of CO_2 emissions per capita, x_{it} is the logarithm of per capita GDP, α_i is individual effects and ε_{it} is the error term.[10]

Similar to many other studies, we do not control for other possible determinants of CO_2 emissions, such as energy prices or technological change. Based on the present analysis, their investigation should be the subject of future research. As pointed out by Azoumahou *et al.* (2006), there are several reasons for this specification. The first is data availability over long time series in terms of additional explanatory variables. Second, this specification allows for a greater comparability with existing studies.

[9] New studies using new datasets and/or new econometric techniques may provide marginal value added; they might include the exploration of fields where evidence is very scarce the analysis of single country panel dataset where within country heterogeneity (region-based) is exploited (List and Gallet, 1999, Carson *and* McCubbin 1997), the inclusion of key explanatory variables in the core EKC model, such as trade factors, which have been increasingly studied (Frankel and Rose, 2005; Cole at al., 2006;), energy factors (Aldy, 2005, 2006), income inequality issues (Torras and Boyce, 1998; Torras, 2005), spatial econometric techniques, to relevant for a public good externality such as carbon dioxide (Maddison, 2005), semi or full non-parametric setting, including Bayesian approaches (Vollebergh *et al.*, 2005; Galeotti *et al.*, 2006; Azomahou et al., 2006; Mazzanti *et al.*, 2009).

[10] We do not exploit cubic specifications here. We believe they are more relevant for emissions that have shown robust TPs at quite low levels of income ($10,000-20,000), such as SOx, Nox and PM. CO_2 and waste generation are still in the phase where investigating an EKC first TP, if any, is the objective of the analysis. 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.

The third reason is more econometrically-oriented: although a specification that excludes other determinants of CO_2 emissions is not appropriate for measuring ceteris paribus the impact of GDP on CO_2 emissions, this kind of econometric specification is very useful for capturing the global effects of GDP on CO_2 including the indirect effects linked to the omitted variables which are correlated with GDP. Moreover, since we are not interested in obtaining the best prediction for CO_2, additional explanatory variables not correlated with GDP are irrelevant.

3.2 Data and samples

As discussed above, we focus on the developed regional areas that have been leading the climate change policy debate. The extension to less developed areas would be related to whether or not they are experiencing at least a relative delinking, given that a TP is not yet a credible hypothesis.

For country groups/aggregations, we adopted the following samples' composition: (a) Australia, Canada, Japan, New Zealand, Norway, U.S.A. (The 'Umbrella group'); (b) Belgium, Denmark, Finland, France, Germany, Netherlands, Sweden, U.K. (EU North); (c) Austria, Greece, Ireland, Italy, PORTUGAL, SPAIN (EU 'south')[11].

Data on emissions are from the database on global, regional, and national fossil fuel CO_2 emissions prepared for the US Department of Energy's Carbon Dioxide Information Analysis Center (CDIAC) (cdiac.esd.ornl.gov). Our database also includes emissions data going dating to 1751 for some countries, and for 1950-2002 for many other world countries, the latter taken from energy statistics published by the United Nations in 2005. For our study, we use the subset of emissions data that matches the available time series on GDP per capita[12] on the basis of joint availability, series continuity, and country definitions. This resulted in a sample of 109 countries for the period 1960-2001, from which we extracted the countries of interest for our study. Table 1 summarises the main variables used and the descriptive statistics.

[11] Russia was excluded from (a) because of problems in recovering the time series. Note that the groups are homogeneous in terms of policy perspectives on climate changes and (hypotheses) on their income-environment relationship. 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, which shows less consensus than the southern EU countries. Some southern countries such as Greece, Spain, and Portugal area associated to Kyoto targets allowing increases of emissions around 20-30%, as well as Ireland that though being a northern country has experienced the same high growth dynamics over the last twenty years as (former) low income countries in the EU. We recall that in 1997 Ireland, Spain and Portugal were still quite undeveloped and with very high rate of unemployment.

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

3.3 Alternative estimators for the macro panel

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

We begin by assessing the (sensitivity of) results, and model performance, across the following five 'homogeneous estimators' (Table 2): Least Square Dummy (LSD) estimator (FEM) allowing for individual fixed effects, as basis; then the Dynamic ordinary least squares (DOLS) estimator for the cointegrated panel data regressions (Kao and Chiang, 2000; Saikkonen, 1991); the PMG estimator proposed by Pesaran *et al.* (1999) which can be considered as an 'intermediate' estimator since it allows intercepts, short-run coefficients and error variances to differ freely across cross-sections while holding long-run coefficients the same,[13] the Driscoll-Kraay (DK) (1998) non-parametric estimator, which corrects the variance-covariance matrix for the presence of spatial as well as serial correlation and can be viewed as a variant of the Newey and West (1987) time series covariance matrix estimator; the GLS estimator of the Seemingly Unrelated Regressions (SUR) specification proposed by Zellner (1962) allowing cross section correlation via the individual error terms; and finally the Dynamic SUR (DSUR) which takes account of cross sectional correlation in a panel cointegrated framework (Mark *et al.*, 2004).

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

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

independence[14] and in all cases they strongly reject the null hypothesis that the errors are independent across countries.

All these estimators allow individual intercepts but common slopes. Although the increase in the time dimension allows us to reject the slope-homogeneity implicit in pooled estimators, there are some features that render homogeneous estimators quite attractive. For example, Baltagi *et al.* (2000, 2002, 2004), find that homogeneous estimators have generally better forecasting[15] performance than their heterogeneous counterparts - mostly due to the simplicity, parsimony and stability of the parameter estimates.

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

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

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

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

(as in the Empirical Bayes) versus Iterative methods (as in the Iterative Empirical Bayes) can be found in Maddala *et al.* (1997).

4. Empirical evidence

Figures 1–3 depict the relationship between CO_2 and income for the three samples. We provide real data, and the curve fitted (non-parametrically) by robust locally weighted scatter plot smoothing (*lowness*). The relationship is clearly monotonic for the Umbrella group and for EU-South but shows an inverted U shape for EU-North countries. It should be noted that, while in some countries this inverted U-shaped pattern is symmetric, in others there is a non-symmetric pattern since the upward-bending portion of the curve does not swing back to the initial level of CO_2 per capita.[16]

Our evidence is mainly concerned with comparison of 'homogenous', and 'heterogeneous' panel estimators, with the emphasis on cross sections correlation and adjustment dynamics.[17] As before, we examine six homogenous panel estimators (FEM as benchmark specification and DOLS,[18] PMG,[19] DK,[20] SUR[21] and DSUR[22]) and 5 heterogeneous based estimators (Swamy, MG, Empirical Bayes, Iterative Empirical Bayes, Hierarchical Bayes). For each specification modelled, we examine the three samples of countries in terms of carbon-income shape (elasticity) and eventual EKC TP, assessing whether this TP is within or outside the range of observed values.

In relation to the first homogenous estimators, we note that the baseline FEM shows that quadratic specifications are significant for all the analysed cases, while the cubic specifications are not.[23] Nevertheless, the evidence is different across groups: while the TP for EU north is within the range of observed values ($13,000) this is not the case for the Umbrella group and EU south, which show similar (slightly higher for EU south) TPs , around $45,000-50,000 per capita.[24]

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

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

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

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

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

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

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

[23] Here, and subsequently, cubic specifications (terms) are never statistically significant as expected.

[24] The maximum value for income per capita is $28,129 per capita for the Umbrella group, $23,160 for EU north and $23,201 for EU south.

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

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

Introducing a certain degree of heterogeneity, as in the PMG estimator, and taking account of cross sectional correlation (DK, SUR, DSUR), do not modify the picture substantially. It should be noted, however, that while the TP estimate for pro-Kyoto countries is very stable across the different methods, allowing for cross-country correlation or for a limited degree of heterogeneity provides lower estimates of the quadratic specification and higher TPs, well outside the range of observations.[25]

To summarise the evidence from homogeneous specifications, apart from the differences in TP for the Umbrella and EU south groups, indicating non-existence of a robust EKC shape, the evidence for EU north is statistically and economically robust and is associated to EKC TPs in the range $11,000 to $14,000 per capita.

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

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

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

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

[25] Note that the DC approach substantially decreases the standard error estimates.

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

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

To sum up, the set of heterogeneous based estimators, Bayesian or not, provide robust evidence of an EKC for the EU north countries and only relative delinking for the other two groups. We note that the consistency of estimates across models (level of the coefficients) is stronger for heterogeneous models, which present lower variability. Also, they show that tackling heterogeneity using specific tools provides a clearer understanding of the income-environment relationship, although we can also highlight that the differences for the group showing EKC shapes (EU north) are slight even when comparing homogeneous and heterogeneous models. Overall, then, our evidence is very robust. We can be confident that the shapes and TPs we estimated are representative of the real phenomenon. Complementary research could include investigation of the country by country income-environment links, based on time series analysis or within country panel regional based analysis (List and Gallet, 1999; Mazzanti et al., 2008).

5. Conclusions

This study has provided new updated environmental Kuznets curve estimates based on long panel data series (1960-2001), exploiting both homogeneous and heterogeneous panel estimators. We focus attention on three groups of countries in the political economy arena related to Kyoto and post Kyoto frameworks: the Umbrella group led by the US, the EU north group, which is the most proactive in climate change issues and the EU south group of countries, which have lower incomes per capita and generally lower level commitment to climate change. We find that the Umbrella and EU south groups which are less in favour of stringent climate policies, have not experienced a 'carbon Kuznets curve', that is, a path characterised by absolute delinking, although there is evidence of relative delinking in the carbon-income relationship, with carbon elasticities with respect to income per capita of around 0.45-0.50. The EU north countries show EKC shapes, with TPs estimated at around $10,000-14,000 per capita. From a methodological point of view, it should be noted that both homogeneous and heterogeneous panel models provide similar evidence, with minor differences across the models examined. However, the latter seem to perform better, insofar as they capture the real shape of Umbrella and EU south countries' relationship, which is linear and not bell shaped with TPs outside the range. In addition, the estimates for heterogeneous panel models are less variable across models. We can conclude that, when focusing on structural heterogeneity, we provide evidence for single countries in terms of the income-environment dynamics, while homogeneous panels inevitably capture the average trends (shapes) for the groups of countries considered, which are more likely to give bell-shaped for output.

On the basis of the different strategic political perspectives on climate change issues proposed by the (groups of) countries in our analysis, we can say that they are clearly based more on political and strategic rationales (strategic behaviour in international affairs, strategic behaviour related to competitive advantage in environmental issues) than on purely economic rationales (marginal costs of abatement). Despite some differences across countries, even within the three groups, consideration of economic rationales, should put greater weight on countries that have not reached a TP in the income-environment relationship. Overall, these countries have more scope for incremental efforts towards abatement of carbon emissions, and lower marginal costs, ceteris paribus. The EU north group has already taken positive action towards tackling climate change, and ceteris paribus, despite possible intra-group heterogeneity, face higher marginal costs of abatement. It would be expected that these countries will be bigger buyers of quotas under the new EU Emissions Trading Scheme (ETS) (Kruger and Pizer, 2004). The evidence we provide gives strong support to the more common hypothesis, that only a fraction of the OECD countries as an aggregate sample, shows absolute delinking, that is, those countries providing evidence of EKC. The reason for their higher commitment to Kyoto principles lie in the (social and policy) choice to acknowledge the opportunities presented by climate change 'markets' (green products, environmental innovation) as a basis for new competitive advantage, based on the production of an (impure) public good such as carbon abatement, combined with economic gains for the economy. Being an early mover in the market may enable these advantages to be consolidated in the medium long run.

Our results are relevant from both an economic and a methodological point of view, and are useful for informing the post Kyoto negotiation round, which will set the framework for the new policy scenario on climate change, as negotiations will be based mainly on the two sides led by the US and the EU, and differences within the EU among the climate change leaders (UK) and the less proactive countries (Italy). 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. We robustly find that cross section dependence has to be accounted for. Future applied works could use heterogeneous panel data estimators allowing cross section dependence which represent a new area of theoretical research in panel data econometrics.

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Table 1- Descriptive statistics

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

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

Table 2 – Homogenous estimators: FEM, DOLS, PMG

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

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

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

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

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

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

(…) means not included given not significance

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

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

(…) means not included given not significance

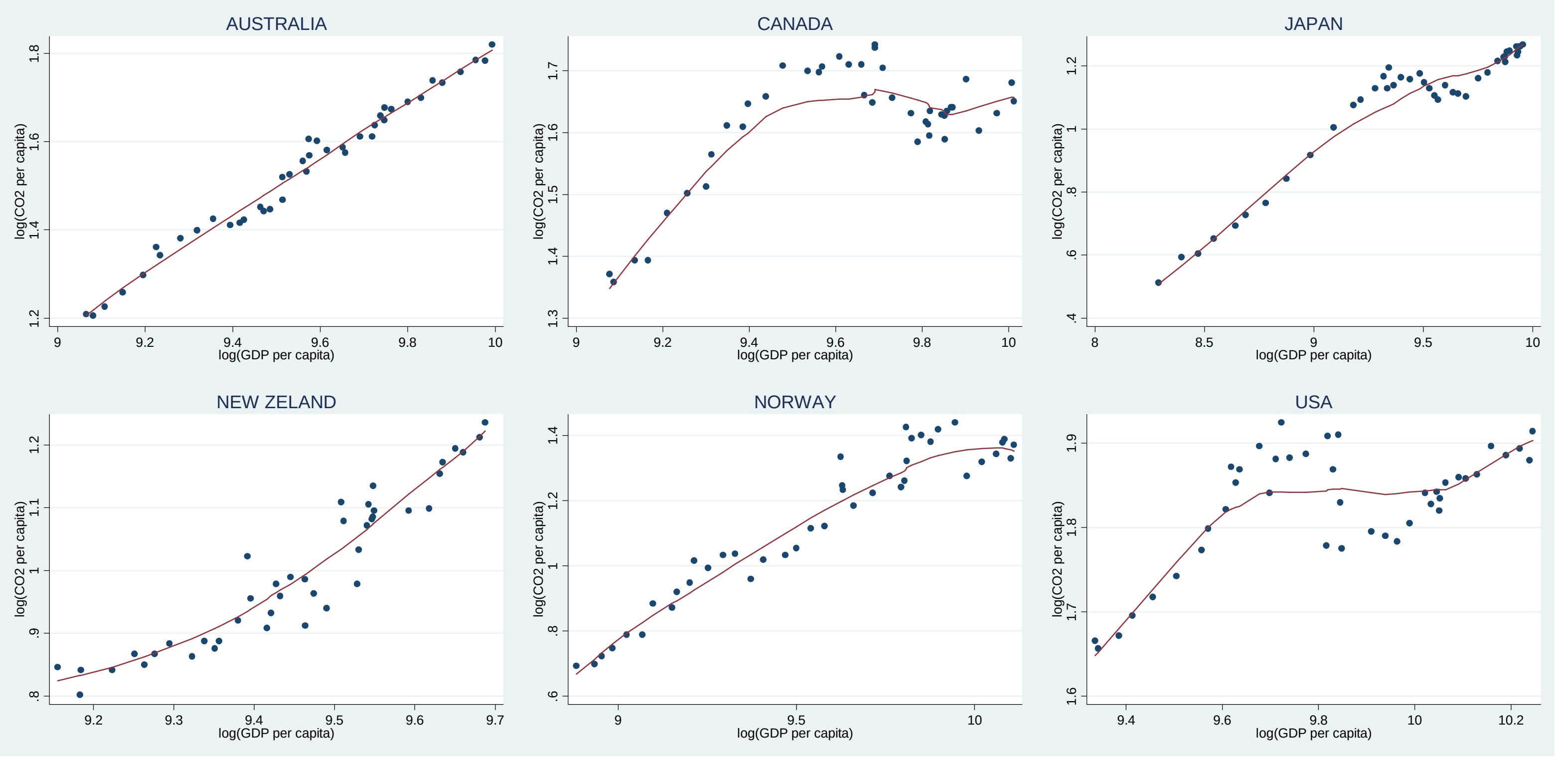


Figure 1. UMBRELLA countries (scatter : real values. Line : robust locally weighted scatterplot smoothing)

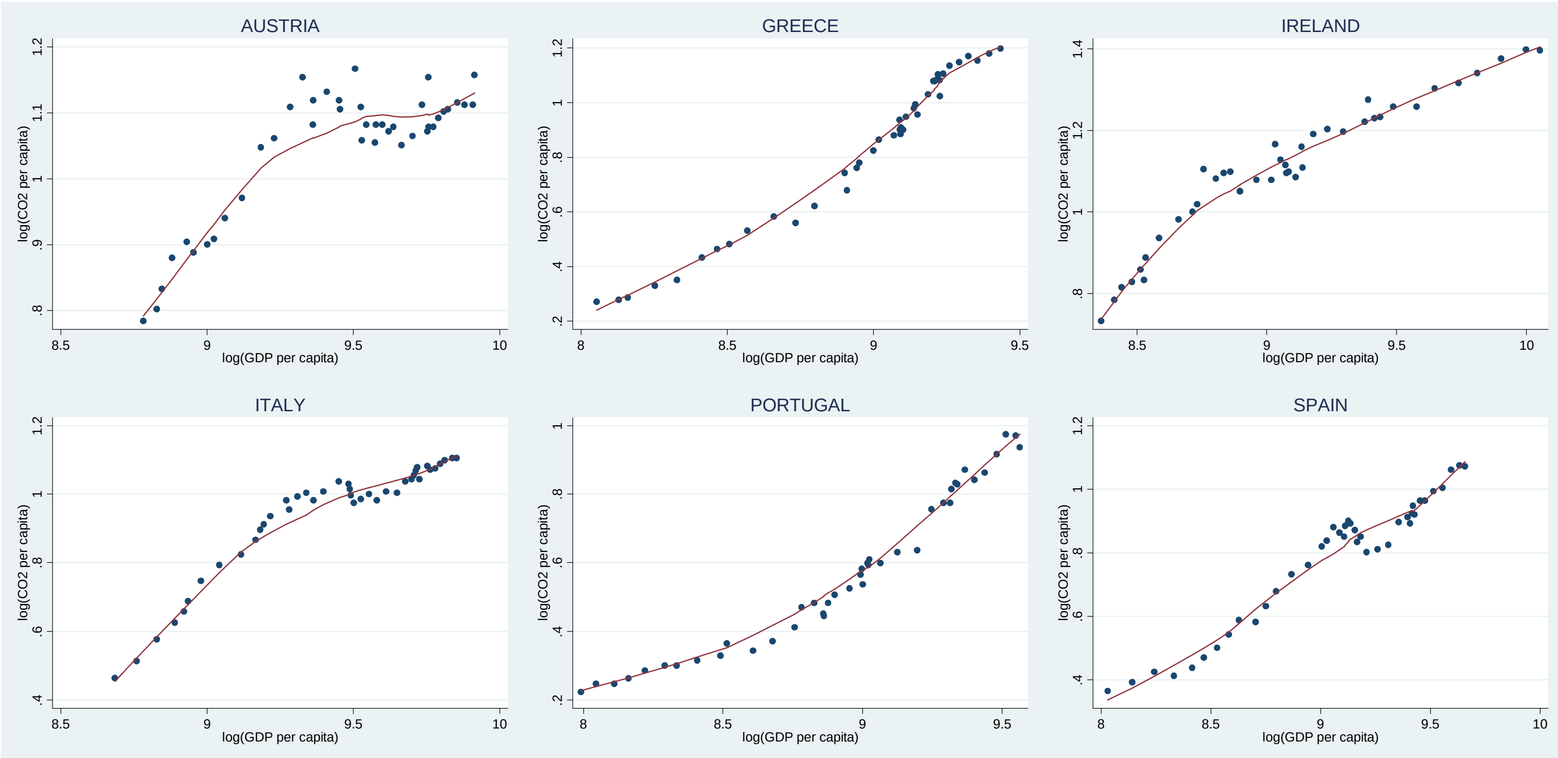
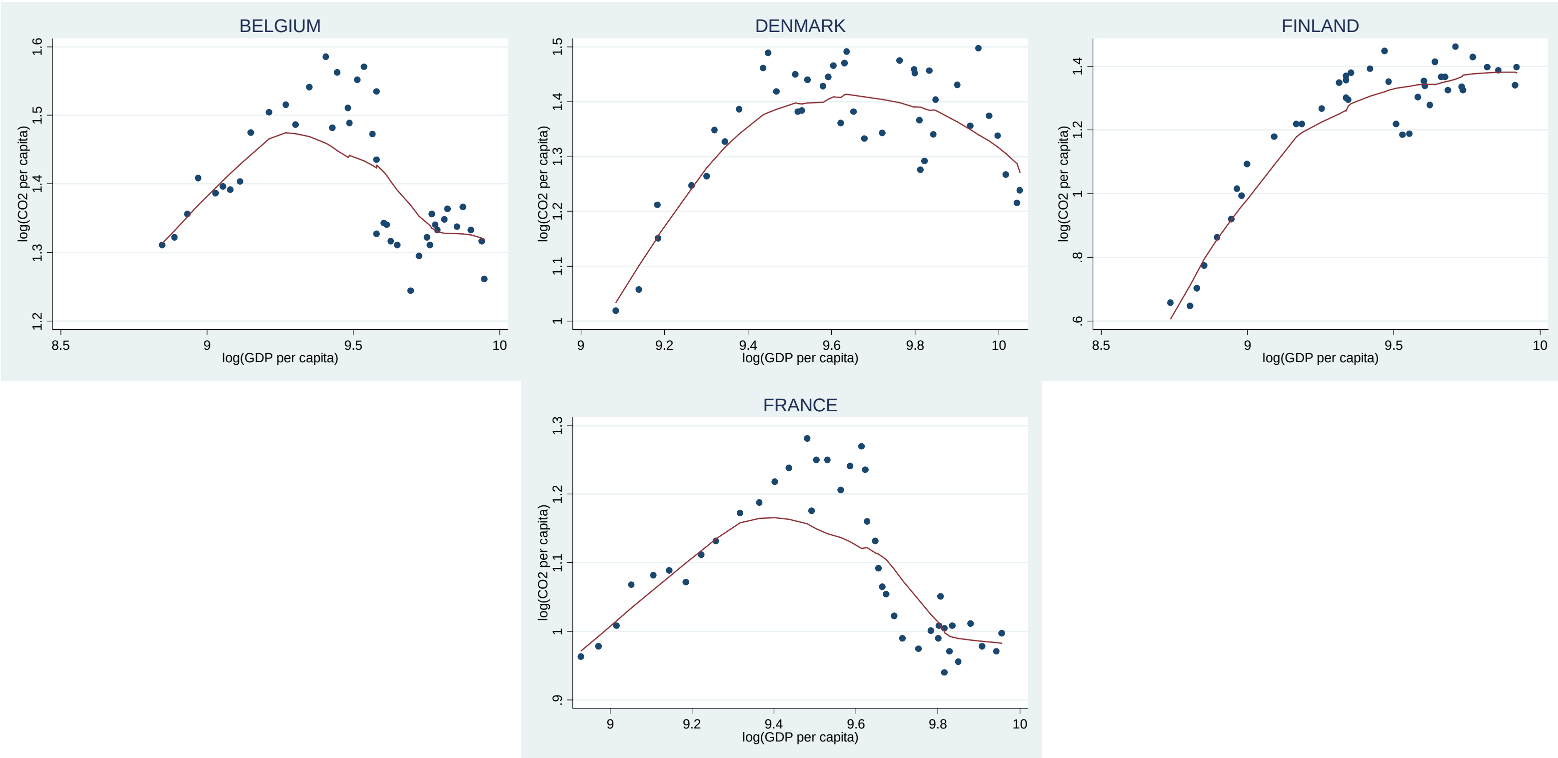


Figure 2. EU-SOUTH countries (scatter : real values. Line : robust locally weighted scatterplot smoothing)


BELGIUM
log(CO2 per capita)
1.2
1.3
1.4
1.5
1.6
8.5
9
9.5
10
log(GDP per capita)
DENMARK
log(CO2 per capita)
1
1.1
1.2
1.3
1.4
1.5
9
9.2
9.4
9.6
9.8
10
log(GDP per capita)
FINLAND
log(CO2 per capita)
.6
.8
1
1.2
1.4
8.5
9
9.5
10
log(GDP per capita)
FRANCE
log(CO2 per capita)
.9
1
1.1
1.2
1.3
9
9.2
9.4
9.6
9.8
10
log(GDP per capita)

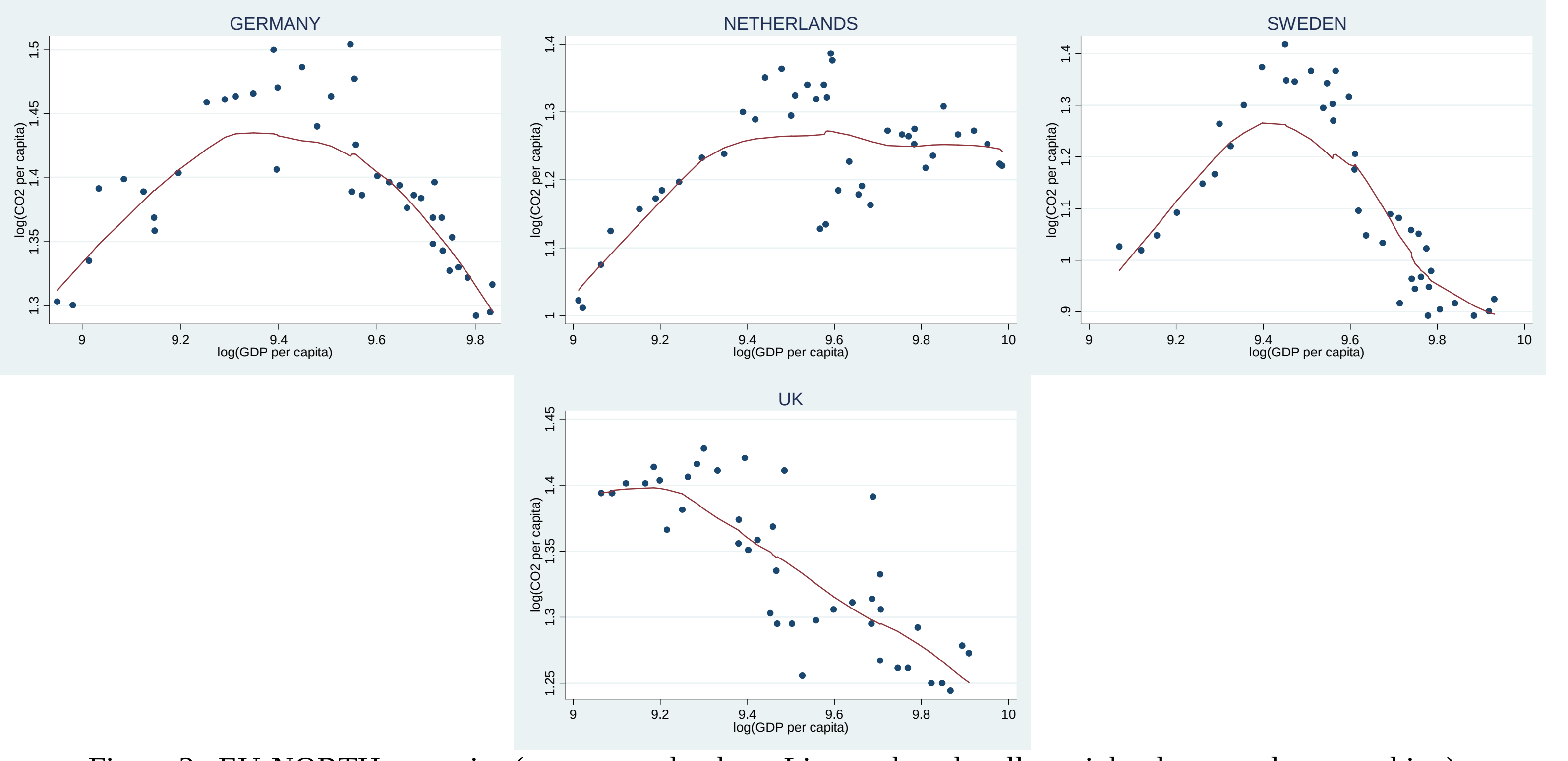


Figure 3. EU-NORTH countries (scatter : real values. Line : robust locally weighted scatterplot smoothing)

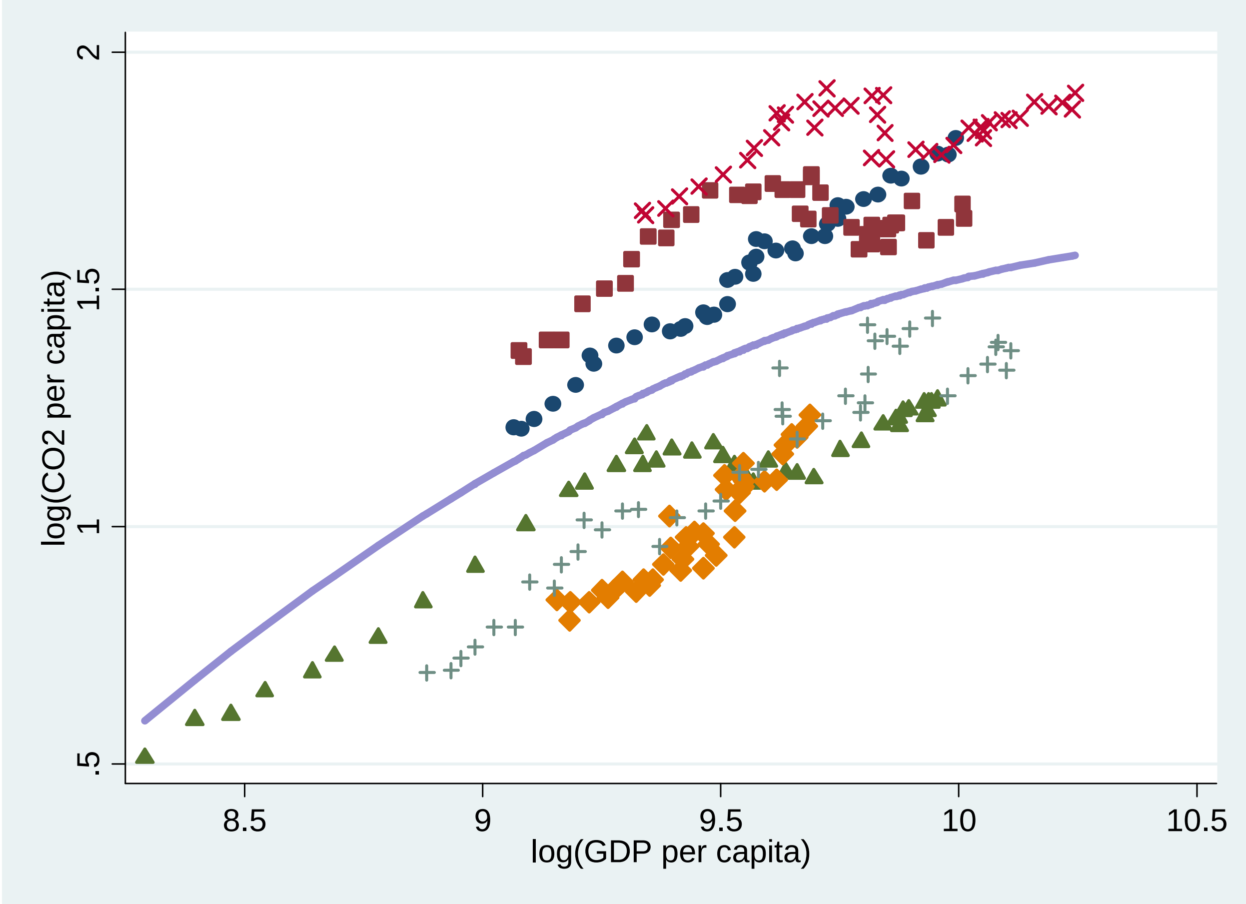


Figure 4. Umbrella countries: real and fitted values with homogeneous (FEM) regression (scatter : real values. Line : fitted values)

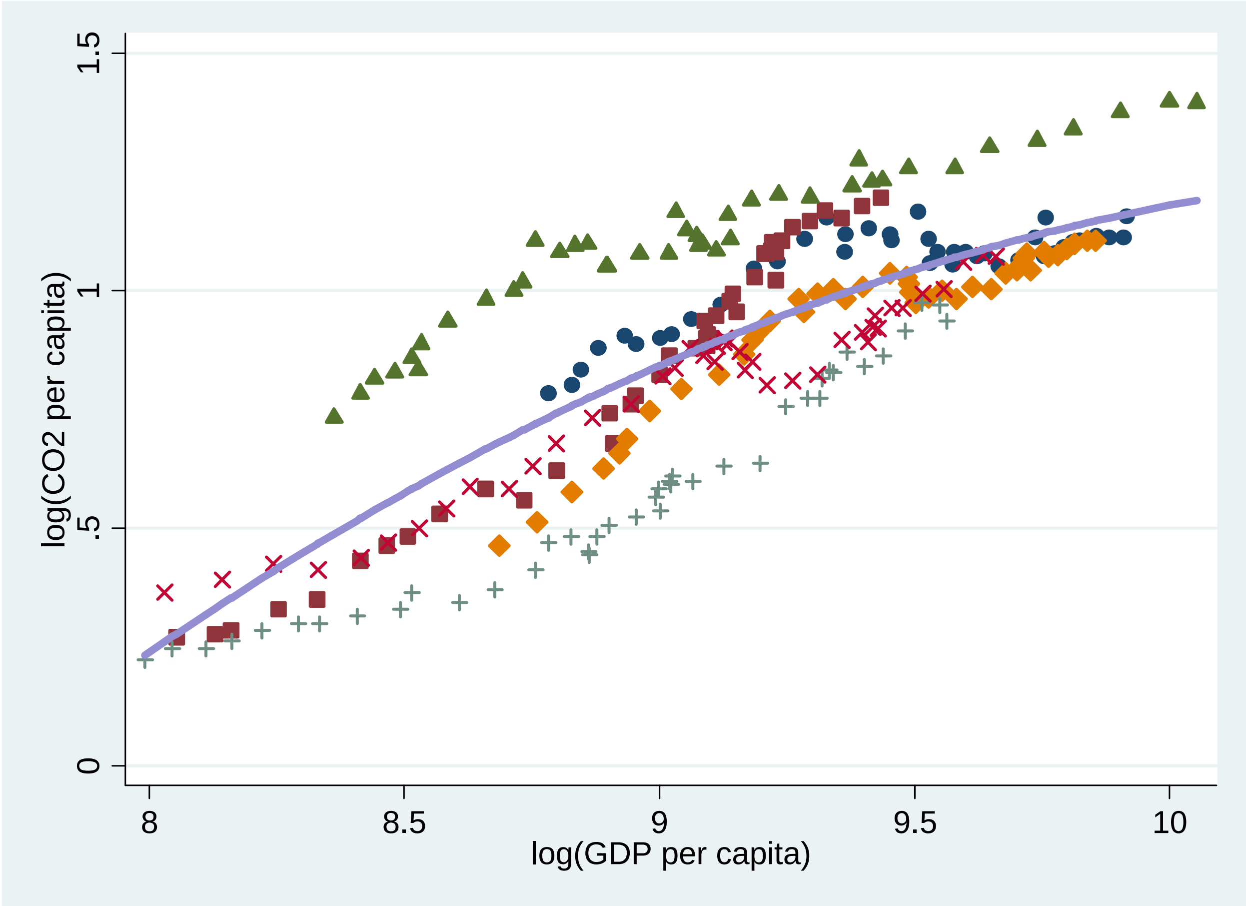


Figure 5. EU-SOUTH countries: real and fitted values with homogeneous (FEM) regression (Scatter : real values. Line : fitted values)