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Abstract

This paper provides new empirical evidence on delinking trends concerning emission-related indicators in Italy. First, methodological issues regarding the analysis of delinking are discussed and the related Environmental Kuznets Curves literature is critically examined to explore and assess the most value added research lines after more a decade of intense research in the field. The main contribution of the paper is that we provide EKC evidence exploiting environmental-economic merged panel datasets at decentralized level exploiting a long times series and rich cross section heterogeneity both at sectoral and Provincial level. This is a necessary and fruitful research direction, following the unsatisfactory outcomes deriving from cross country analyses, which are less informative for policy purposes given they produce average figures for the environmental-economic relationship. Two panel datasets concerning (i) 1990-2000 emissions at Province level (ii) and sectoral disaggregated NAMEA emissions sources over 1990-2001, are analyzed.

We find mixed evidence in support of the EKC hypothesis. Inverted-U shaped curves for the period here considered arise for some of the pollutants in the NAMEA data, like CO_2, CH_4 and CO, with coherent within range turning points. Nevertheless, other emission trends show a monotonic relationship, or in some cases an N shaped relationship (SO_X, NO_X, PM10). Other emissions show relatively less robust results, with mixed evidence arising from different specifications. This partially confirms some of the criticism on the EKC empirical investigation that has recently mounted. All in all, nevertheless, our analysis show that probably the key point is that it does not exist an EKC dynamic, but many EKC dynamics, differing by (i) period of observation; (ii) country/area; (iii) emissions/environmental pressures; (iii) sectors.

In fact, a sectoral disaggregated analysis highlights that aggregate outcome should hide some heterogeneity across different sectors. Services tend to present inverted-N shapes in most cases. Manufacturing industry shows a mix of EKC inverted-U and N shapes, depending on the emission considered. The same is true for industry (all industries, not only manufacturing industry): though a turning point has been experienced, N shapes may lead to increase of emissions with respect to very high levels of the income driver.

The analysis on provincial data shows that inverted-U shapes curves arise for some of the emissions in the SINAnet-APAT database, like CH_4, NMVOC, CO and PM10, with coherent within range turning point. Other emission trends show a monotonic relationship (CO_2 and N_2O), or in some cases an inverted-N shaped relationship (SO_X and NO_X).

This kind of analysis at level of macro sector and/or specific sector appear to be the most promising and robust field of future research for the assessment of EKC dynamics. National studies grounded on geographical heterogeneity, instead of regional/international analysis, and focused on sectoral trends, are more informative for economic and policy implications. The implementation of such investigations nevertheless needs larger datasets, currently not available. We thus point to the need of spending increasing and constant efforts in the construction of integrated environmental/economic statistical accounts.

Jel: C23, Q38, Q56

Keywords: Decoupling, NAMEA Emissions, Economic Drivers, Kuznets Curve, Environmental Efficiency

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1. Introduction

Indicators of 'decoupling' or 'delinking', that is improvements of environmental/resource indicators with respect to economic activity indicators, are increasingly used to evaluate progresses in the use of natural and environmental resources. OECD is doing an extensive work on decoupling indicators for reporting and policy evaluation purposes (OECD, 2002). Various decoupling or resource efficiency indicators are included in the European Environment Agency's state-of-the-environment reports (EEA, 2003). A few European countries started to include delinking-oriented indicators in official analyses of environmental performance (DEFRA/DTI, 2003). Some countries are considering delinking-based targets for major environmental policies, and the US adopted an 'emission-intensity' target for their climate policy.

Delinking trends are under scrutiny since decades for industrial materials and energy in advanced countries[1]. In the 1990s, research on delinking extended to air pollution and GHG emissions, also proposing 'stylised facts' on the relationship between pollution and economic growth named as 'Environmental Kuznets Curve' (EKC), due to their similarity with Kuznets (1955) suggestions on long-run income distribution paths[2]. The EKC hypothesis is the natural extension of delinking analysis. The hypothesis is shortly that for many pollutants, an inverted-U shaped relationships between per capita income and pollution is documented. The hypothesis does not originally stem from a theoretical model, but it has followed a conceptual intuition, though recent contributions have started showing the extent to which the Environmental Kuznets hypothesis may be included in formalised economic models[3]. Despite increasing applied research efforts, empirical evidence from EKC on emissions, however, is still ambiguous. Some pollutants, mainly associated to a regional/local impact, seem to show a 'turning point' at certain levels of income, but it is a shared view that some critical externalities, like CO_2 emissions and waste flows, are monotonically rising with income. At best, a 'relative delinking' may take place (Stern, 2004)[4].

The paper aim is twofold. First, we present empirical evidence on EKC dynamics concerning emissions accounting for Italy considered in the National Accounts Matrix including Environmental Accounts (NAMEA), using the available database 1990-2002[5] recently updated by tha National Institute of Statistics (ISTAT). A novelty is that we exploit NAMEA accounting, which is a panel of observations for emissions produced by several productive branches of the economy (Femia and Panfili, 2005). We use a disaggregation in 29 branches[6] for which we observe emissions in the aforementioned period.

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[1] For the extensive evidence until the early 1990s see Tilton (1988, 1991) on metals/materials, Martin (1990) on energy, and Zoboli (1995) for a selective review and discussion. For recent thorough analyses of the long run trends for energy see Ayres et al. (2004), Gruebler et al. (1999) and many other works by IIASA, www.iiasa.ac.at.

[2] Among the early works on pollution, see Holtz-Eakin and Selden (1992), Ten Kate (1993), Selden and Song (1994), Grossman and Krueger (1994).

[3] See Andreoni and Levinson (2001), Chimeli and Braden (2005) and Kelly (2003), who finds that the EKC shape depends on the dynamic interplay between marginal costs and benefits of abatement.

[4] Delinking may occur on a relative basis (the elasticity of the environmental impact indicator with respect to an economic driver is positive, but less than unity) or on an absolute basis (when the elasticity becomes negative).

[5] We used the years 1990-2001 without considering 2002 due to different estimation methodology between the period 1990-2001 and the year 2002.

[6] We are prevented from using the full breakdown into 50 branches, given accounts were not available for all such branches in the first years. Data losses should have been too large. We decided to structure the panel assigning equal weights to temporal and cross section heterogeneity, instead of biasing towards the latter with a shorter but larger dataset.

Secondly, we present a complementary evidence using the same emissions considered in the NAMEA data at geographical level (and not at sectoral level). To date, provincial emissions for 3 years (1990, 1995, 2000) are available from official statistics. In this case, we merge this database with provincial value added (see par.3 for details about the data). Those two pieces of evidence constitute, in our opinion, an original contribution within the EKC literature, since we provide empirical evidence using data at national level, by exploiting two different desegregation (on sectoral and on geographical basis) which may provide a higher heterogeneity and then more robust result.

We will stress that the research on EKC is more and more moving towards analysis at national or regional level. They are both more informative for policy makers, since they capture the specific dynamic of the country, which may differ from the average dynamic observed by cross country panel data investigation, and more robust in statistical terms since they exploit data sources associated to stronger heterogeneity.

The paper is structured as follows. Section two sets out the EKC framework, briefly discussing the main methodological and empirical issues. A survey of main recent works will be presented in order to define what the state of the art is and where one can find new value added. Section three presents and discusses the two emissions' datasets we here exploit. Section four presents the empirical model and main applied findings. Section five concludes.

2. Delinking, environmental efficiency and the EKC framework

2.1 Defining a proper use of delinking and EKC analyses

Relationships between 'delinking' and EKC approaches, and some limitations of both, can be discussed in the framework of a simple IPAT model. The latter defines total impact (I, i.e. athmospheric emissions or waste production) as the (multiplicative) result of the impacts of population level (P), 'affluence' (A), measured by GDP per capita, and the impact per unit of economic activity (i.e. I/GDP) representing the 'technology' of the system (T), thus $I=P\bullet A\bullet T$. This is an accounting identity suitable for decomposition exercises aimed at identifying the relative role of A, P, and T for the observed change of I over time and/or across countries.

While the meaning of the P and A as drivers of I is clear, the exact meaning of T deserves attention. It is an 'intensity' indicator, which measures how many units of Impact (natural resource consumption) are required by an economic system for 'producing' one unit (one dollar) of GDP. As a technical coefficient representing the 'resource-use efficiency' of the system (or, if its reciprocal GDP/I is taken, its 'resource productivity' in terms of GDP), it is the most aggregate way for representing the average 'state of the technology' of an economy *in terms of* the Impact variable. Changes of T, for a given GDP, reflect a combination of shifts towards sectors with a different resource intensity (from manufacturing to services) and the adoption/diffusion, in a given economic structure, of techniques with a different resource requirements (inter-fuel substitution in manufacturing). If T decreases over time, there is a gain in environmental efficiency, or resource productivity, and T can be directly looked at for delinking analysis. By being responsive to changes of the 'state of technology' also influences by markets and policy actions; T is the main 'control variable' of the system. In a cross-country setting, T has a less clear-cut interpretation, but delinking can emerge again as a negative relationship between I and the level of GDP or GDP/P.

In an IPAT framework, three aspects of 'delinking analysis' and 'EKC analysis' emerge more easily.

Firstly, delinking analysis or the observation of T alone can provide ambiguous suggestions. A decrease in the variable I over time is commonly defined as 'absolute decoupling', even though a decrease of I does not, in itself, represent a delinking process as it says nothing about the role of economic drivers. An environmental Impact growing less (or diminishing more) than economic drivers, i.e. a decrease of T, is generally defined as 'relative delinking'. Therefore, 'relative delinking' might be strong, while 'absolute delinking' might not take place (i.e. I is stable or increasing) if the increasing efficiency is not sufficient to compensate for the 'scale effect' of other drivers.

Secondly, a delinking process, i.e. a decreasing T, suggests that the economy is more efficient but, in itself, does not provide explanations on what is driving the process. In its basic accounting formulation, the IPAT framework implicitly assumes the drivers are all independent variables. However, the evidence on dynamics of economic systems suggests that *each* driver as well as the Impact can be reciprocally interdependent through a network of direct/indirect causation. For example, evidence suggests that population dynamics (P) depends on GDP per capita (A), and *vice versa* to some extent. Similar relationships or inverse-causation effects are also relevant for T. Theory and evidence suggest that T can, in general, depend on GDP or GDP/P, and *vice versa* if T refers to a key resource as energy. But also a relationship between changes of P and I and T dynamics can be highlighted (Zoboli, 1996). In particular, in a dynamic setting, I can be a driver of T as the emergence of natural resource/environmental scarcity stimulates invention, innovation, and diffusion of more efficient technologies through market mechanism (changes of relative prices) and policy actions, including price- and quantity-based 'economic instruments'. The re-discovery of the Hicksian 'induced innovation' hypothesis represents the attempt to capture the channels by which I influence T, while models including 'endogenous technological change' can capture some influences of both I and GDP on T. In fact, improvements of T for a specific I can also stem from general techno-economic changes, e.g. 'dematerialisation' associated to ICT diffusion, which are not captured by resource-specific 'induced innovations' mechanisms and can be very different for given levels of GDP/P because of the different innovativeness of similar countries. Then, a decrease of T can summarise micro and macro non-deterministic processes also involving dynamic feedbacks, on which economics has provided a still open set of interpretations.

Thirdly, 'environmental Kuznets curve' analysis addresses exactly one/two of the above relationship, i.e. between I and GDP or between T and GDP/P. It presents 'benefits' and 'costs'. Even though it may provide empirical regularities having great heuristic value, it may not provide satisfactory economic explanations. We recall that the EKC hypothesis is that the concentration/emission of a pollutant first increases with the economic driver, as a 'scale effect' prevails, then starts to decrease more or less proportionally, thus it de-links itself from income due to a steady improvement of T. More specifically, the hypothesis predicts that the "environmental income elasticity" decreases monotonically with income, and that it eventually changes its sign from positive to negative thus defining a turning point for the inverted-U shaped relationship. We do not address here the very different meaning of the various formulations of the EKC hypothesis, which range from a relationship between I and GDP to a relationship between T (I/GDP) and GDP/P. Let us note that if the relationship is between I and GDP, the EKC provides the same information as the analysis of T. Furthermore, if there is an EKC between I and GDP, there should be also one between T and GDP because both P and GDP are, with some exceptions, increasing over the long run, and delinking must have occurred at some level of GDP. Instead, if there is an EKC between T and GDP or GDP/P, not necessarily there is also one between I and GDP, because GDP and P might have pushed I more than the 'relative decoupling', i.e. decreasing T, has been able to compensate for. The latter is the case of global CO_2 emissions in the very long run. When relying on GDP or GDP/P as the only explaining variable, ECK suffers from the same issues highlighted above for delinking analysis, but with an additional risk. The existence of an EKC could give the wrong deterministic suggestion that a rapid growth towards high levels of GDP/P *automatically* drives to environmental efficiency, i.e. 'absolute' o 'relative' delinking, and then it can the 'best policy strategy' to reduce environmental Impact. But, from the IPAT framework, it is clear that GDP or GDP/P growth by itself also implies a 'scale effect' on I, i.e. a growth of the Impact at each level of T (and P).

2.2 Estimating Environmental Kuznets Curves: Key issues

The EKC framework extends the basic decoupling reasoning, modelling a multivariate analysis of the environment-income relationship[7]. We refer to the EKC framework as the field of analysis which empirically studies, without a defined theoretical model in mind, but rooting on Kuznets seminal work and, whether or not an inverted-U shaped curve is observed for pollutants and other environmental indicators. Even if EKC does not rely on a specific economic model, many theoretical assumptions, on the consumption and production sides, are implicitly tested within the EKC empirical context. The main economic hypothesis revolving around the EKC setting are: (i) among the "negative effects" of income increase, we find a typical scale effect, and (ii) among the "positive effects" we find a composition effect concerning GDP economic activities, a technological effect, a preference-drive effect (environment being a normal/luxury good), and a market-instruments driven effect (which is integrated with the wider policy effect).

Knowing the benefits of a EKC multivariate econometric-based analysis, we have to be fully aware of the costs, then trying pragmatic ways for mitigating them. It is necessary to draw out what the main EKC deficiencies and weaknesses are.

We may note that careful attention should be paid to deriving policy implications. In fact, EKC studies often use different environmental index (absolute, per capita, output based, input based, per unit of GDP). A general consensus over what indicators to use does not exist. Different measures have nevertheless different implications and interpretation. For example, while a measure on per capita basis in OECD countries faces few problems of understanding, and absolute measures could be avoided, if we measure intensity in the vertical axis the presence of a lower bound implies that total emissions are growing at the same rate of income, in a sort of "steady state" equilibrium. Thus, it is obvious that the measures on the vertical and horizontal axis should be compatible to each other. We also note that there is no consensus about the type and number of explanatory factors introduced as potential drivers of the environmental performance. Some studies use income variables only. Other studies

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[7] We suggest that the EKC framework is, under certain circumstances, a necessary step forward the simplest decoupling analysis. Multivariate investigations add robustness to results. Nevertheless, the potential weaknesses of the EKC analysis will be thoroughly highlighted.

include many socio-economic variables with the (correct) aim of extending the conceptual setting behind the EKC empirics (Harbaugh et al., 2002); a few ones include policy drivers (Markandya et al., 2004). The choice obviously depends on both data availability and research objectives.

The nature and quality of data are also crucial issues. In fact, for reasons linked to existing data availability, the first wave of the EKC literature has witnessed a large majority of contributions which focussed on the analysis of cross-country datasets, generally taken from official OECD and World Bank sources. Nevertheless, firstly the quality of macro data for some regions (non OECD countries) has been questioned, and secondly, even the exploitation of panel datasets does not allow the researcher from calculating specific country-level coefficients for the income-environment relationship. The conceptual key fact is that not a single relationship, but many different, may apply to different categories of countries. In other words, the policy relevance of world-wide cross country analyses seems limited. Future research, as it will be stressed in the conclusions, should then focus on delinking analysis that exploit datasets regarding environmental and economic indicators at a provincial/regional level (at national/European level). It follows that a higher value added is going to be found in studies based on national/regional rather than international datasets[8]. The more the evidence is micro-based (regionally/locally disaggregated) the better it is for statistical and policy aims.

This paper aims at providing new evidence along this line. We argue that the two most value added research lines are, as also emerging from the literature commented just below, the following: one is concerned with the comparison of parametric and non parametric models thus testing the relevance of the functional forms (and within the parametric world of homogenous and heterogeneous panel specifications); the other, which is not automatically separate, goes towards empirical evidence grounding on national case studies disaggregated at regional level. One emerging results is in fact that, for most environmental pressures, large cross country datasets do not provide sound outcomes, independently from their statistical robustness; the main reason is that different EKC shapes may be associated to the different units of the sample under analysis. More interesting suggestions, rich of economic and policy relevant interpretations, may stem from database for homogenous set of countries or even better national case. The EKC may in the end be country specific.

2.3. EKC analyses: recent evolutions

2.3.1 Introduction

We refer to Ekins (1997), Dinda (2004, 2005), Cole et al. (1997), Cole (2003), Stern at al. (1996), Stern (2004), Managi (2006), Fonkych and Lempert (2005) and Yandle et al. (2002) for extensive critical surveys of the literature. The first sections quoted some of the seminal papers in the delinking and EKC literature.

We here briefly critically comment some of the new contributions emerged in the field, on the basis of the value added that they provide concerning methodological issues and new empirical evidence on EKC dynamics for major emissions/environmental pressures. The focus is primarily on major emissions and, among those, on CO_2

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[8] The point is also commented in Bimonte (2002) who exploit a cross sectional dataset of European countries concerning national area devoted to nature conservation and national parks. Other OECD countries are dropped for reasons of data commensurability and homogeneity. For emissions, the problem is less severe, though it remains true that value added in statistical and policy term is higher when focusing on more homogenous cross country or within a country datasets.

studies which are usually leading, given the policy and environmental relevance of the problem and the higher availability of data at international level. The purpose is to update the empirical state of the art by commenting on most recent studies, in order to highlight what the current streams of research within the EKC framework are, and to collocate our investigation with respect to the recent empirical contributions.

As summarised and showed by Cole at al. (1997) and Stern (1998), the evidence of the first wave of studies, relying on data until the late eighties, was generally that EKC existed only for local air and water pollutants, but not waste, while indicators with a more global or indirect effect were increasing more or less monotonically with income. Empirical evidence of various nature in support of an EKC dynamics, or delinking between emission and income growth, has shown to be more limited and fragile concerning CO_2 with respect to local emissions and water pollutants (Cole et al., 1997; Bruvoll and Medin, 2003). Decoupling of income growth and emissions of CO_2 is not (yet) apparent from the facts for many important economies in the world (Vollebergh and Kemfert, 2005), and when delinking is observed, it is mostly of a relative and not of an absolute kind, as assumed by the usual EKC hypothesis (Fischer - Kowalski and Amann, 2001[9]).

We note that recent works have highlighted, on the basis of newly updated data and new techniques, that some evidence, even if patchy, differentiated by geographical area and by estimation techniques, is emerging (Martinez-Zarzoso and Morancho (2004), Vollebergh and Dijkgraaf (2005), Vollebergh et al. (2005), Cole (2003), Galeotti et al. (2006). Though evidence is heterogeneous across various attempts (which use dissimilar data with respect to time span and countries), it may be affirmed today that, at least as far as OECD countries are concerned, some EKC evidence even for CO_2 is slowly emerging. A more optimistic picture is then arising, counterbalancing some other less optimistic views (Harbaugh et al., 2002; Stern et al., 1996; Stern, 1998, 2004). Nevertheless, it is worth noting that a robust assessment of results is under way. Some critical points and ambiguous heterogeneity across models and different contributions still remain.

Our survey is specifically focused on the largest stream of analysis which deal with atmospheric emission related environmental issues, though some reference is provided for other issues like material flows and waste production. Given the strong heterogeneity of studies with respect to methodology, environmental issues and geographical focus, it is not easy to organise a brief survey of recent works. Contributions are thus organised in a table (Table 1) in which we consider the aforementioned issues (methodology, the environmental pressure considered, the nature of the data and the evidence). Then the surveyed papers are commented following a narrative reasoning.

2.3.2 From standard panel analyses towards time series and semi / non parametric models

There are a series of recent papers which provide various empirical evidence by exploiting more flexible panel parametric specifications and non parametric methods. Martinez-Zarzoso and Morancho (2004) analyse CO_2 data covering the period 1975-1998 for 22 OECD countries by applying the pooled mean group estimator, that allows for slope heterogeneity in the short run imposing restrictions only in the long run, also allowing for dynamics. Slope homogeneity may be a serious constraint in panel data analysis when the evolution of

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[9] The paper, which is strictly linked and refer to Matthews et al. (2000), presents descriptive quantitative evidence on material, waste and emission flows, from a perspective of material input-output accounting. The richest OECD countries are taken as examples.

environmental and economic factors is strongly heterogeneous across countries, and accounting for fixed effect country differences is deemed not sufficient. The cubic specification is tested with and without time trend for comparative purposes. They find that the cubic model is best performing, implying a N shaped dynamic, with turning points varying from a low of 1577$ to a high 32009$ per capita. The squared specifications lead to EKC turning points between 4914$ and 18364$ per capita: squared specifications seem also to fit better with developing countries data concerning 19 Latin American and Caribbean countries. Summing up, evidence is favouring N shape for the majority of OECD countries and EKC inverted-U shape for less developed countries. The range of implied turning points is nevertheless too wide to lead to some conclusions.

Auci and Becchetti (2006), starting from Harbaugh et al. (2002) paper, which demonstrate the lack of robustness of EKC when countries, variables and intervals are changed, also presents recent evidence on CO_2, building on 197 countries from the WDI dataset, over 1960-2001. The paper provides slightly new evidence since it specifies as dependant variable CO_2 per unit of GDP instead that CO_2 in per capita terms. Data include emission from aggregate fossil fuels consumed by domestic systems. This allows the assessment of supply side effects, like scale and technology factors, which may represent the main explanation behind the EKC[10]. The hypothesis is that GDP may capture by correlation the underlying effect of economy restructuring, which is, in the end, the ultimate factor driving the elasticity from positive to negative[11]. They thus include as additional determinants of emissions variables like sources of energy production, proxies of agricultural activities, population density, fuel import. Then, the model is estimated on the overall period and in 20-year moving windows to investigate more fully the dynamics of EKC. EKC evidence is found for base and extended specifications, with turning points above the mean income level. Changing intervals by using rolling estimation does not affect EKC results. The introduction of energy supply variables sharply improve estimates; the prediction and policy implication is that, in correlation to GDP growth, more environmentally friendly ways of producing energy, new sources of energy, an improved distribution of income and an increased share of service value added in the economy are all relevant drivers of a decoupling between CO_2 and economic growth. Though all this factors are probably interrelated, and captured in the end, with some country specific heterogeneity, by GDP growths, the paper presents additional evidence on the latent driving forces of decoupling along the development path. Soytas et al. (2006) also include energy consumption in their EKC model, providing evidence for the US of a striking role of energy dynamics.

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[10] For example, see Managi (2006).

[11] On the same line, Liaskas et al. (2000) present evidence on a delinking between GDP and CO_2 emissions in the EU, which is strictly linked, according to their decomposition of industrial emissions, to a delinking between industrial ouput and energy use which translates into the EKC income environment inverted-U shaped relationship. While a secondary relevant effect is attributed to the changing fuel mix, primarily from oil to a natural gas and also renewable energies, there is no evidence of significant effects of economy restructuring on the delinking at EU level.

Horbach (2002) focuses on an empirical analysis of structural change between economic branches as one major determinant of EKC. Merlevede et al. (2006) take another look at structural features of the economy, by testing the hypothesis that average firm size associated to a country matters for EKC. Using UNIDO industrial statistical data for 45 countries over 1981-1992 and SO_2 data, as long as other variables used by Harbaugh et al. (2002), like democracy, income, trade openness, they find a N shaped dynamic for the pollutant. Firm size is significant as driver, with a positive sign on the coefficient: large firm countries tend to influence the pollution-income relationship in association with the implementation of policies; the two terms may be correlated to each other. This evidence may signal that eventual economies of scale associated to large firms are counter balanced by an average less stringent environmental policy in those countries. The significance of the interaction between size and GDP suggests that the slopes are different from large and small firm countries.

Cole (2005) also analyses OECD data by assuming slope heterogeneity within a random coefficient model. Data are referring to SO_2 and CO_2 emissions (110 countries, 1984-2000), NO_X (26; 1975, 1980, 1985, 1990). He finds EKC evidence when staring from the restrictive fixed effect model, though sensitivity of results to different samples is observed. The random coefficient model instead shows that only NO_X data supports EKC evidence. For all pollutants, OECD only and non OECD data show different outcomes. This suggests that the assumption of homogenous slopes may be inappropriate, being the EKC dynamic not common across countries[12].

Country specific analysis or in depth analysis on homogenous areas (EU, US) may be more fruitful in providing sound evidence and food for policy thought. For example, as far as emissions are concerned see Carson et al. (1997) and List and Gallet (1999), who both focus on US state level data, highlighting inevitable problems of data comparability and quality when using a wide spectrum of countries. The first study find strong evidence of a decrease for seven major pollutants with respect to per capita income.

It is worth focusing on the second study by List and Gallet, who present evidence on the US using state level SO_2 and NO_X emissions from 1929 to 1994. The empirical model allows states to have heterogeneous slope and intercept parameters. We claim that the investigation of EKC using within country heterogeneity in panel or time series frames, is a fruitful research line, obviously dependant on data availability, but that could provide more robust insights with respect to country based international datasets. Their results provide evidence of a EKC curve taking the overall panel frameworks, estimating two models, one allowing for intercept heterogeneity and the other also slope heterogeneity: turning points are well within the range for NO_X (estimates range from around 8000$ to 17000$ across models), while for SO_2 are at the boundary (ranging from 15000$ to 20000$ per capita, 1987 US$). Focusing on single time series they estimate specific EKC for each state: they interestingly group states according to the comparison of their specific EKC turning point, with respect to the confidence interval for the overall average turning point. In summary, the large majority of states follow a EKC shape, predominantly in quadratic rather than cubic form, and with a larger share of states for NO_X. Then, turning points predicted by the traditional panel model are lower than the peaks observed state by state. Most states though associated to a EKC shape witness higher than the average turning points. Thus, traditional panel analysis may lead to overly optimistic conclusions, driven by the result which represent the average picture, hiding specific EKC dynamics by states or regions within countries. All in all, heterogeneity is by itself a value added: panel data grounded on within country heterogeneity adds robustness to results. Single time series may provide further evidence on EKC heterogeneity.

A criticism on "homogenous" panel, note accounting for specific effects, was also raised by Diikgraaf and Vollebergh (2005) and Vollebergh et al. (2005). The first paper casts doubt on EKC results stemming from homogenous panel estimation. They use a usual sample of 24 OECD countries over 1960-1997. On this basis they challenge the existence of an EKC dynamics for CO_2, at least for the overall picture of OECD countries, and suggest more in depth investigation at country specific level. Traditional panel models with country specific or country and time effects present turning points at around 14-15000$, nevertheless the null hypothesis of slope homogeneity is strongly rejected by data. A general model with slope heterogeneity show an higher turning point (20600$), all are in any case within the sample range. The most striking results is nevertheless that time series

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[12] We note that the superiority of heterogeneous panel data models is questioned. See Baltagi et al. (2002).

analysis, compared to heterogonous panel estimations, present a different picture. Only five out of 13 countries that showed an EKC dynamics confirm this outcome. They conclude that more work should be done on time series data, provided sufficient availability[13] (as example, Egli, 2002).

Vollebergh et al. (2005) consequentially explore various parametric and non parametric specifications for a CO_2 dataset concerning OECD countries (24 countries, 1960-2000) and finds that EKC shapes are quite sensitive to the degree of heterogeneity included in panel estimations, further remarking the need of exploring not only heterogeneous panels specifications but also more flexible estimation tools. Parametric models generate EKC shapes with quite low turning points, while evidence is less robust for semi parametric estimations. In addition, they note that few observations on upper income and often small countries (i.e. Luxembourg) may produce strong effects on the EKC shapes. Thus, weighting is another issue that may undermine (homogenous) panel results. The non parametric setting demonstrates the necessity to incorporate heterogeneity, that leads to the exploration of single country specific time series, and to the suggestion of treating with care panel based EKC outcomes, moreover if they do not address in one way or another the heterogeneity issue.

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

Besides the criticism on panel data estimation, which also refers to the contributions by De Bruyn et al. (1998), another (entangled) line of criticism is based on the sensitiveness of results to the (parametric) specification used. One leading paper showing the higher robustness of semi parametric models with respect to traditional panel structures is by Millimet et al. (2003). They exploit a long 1929-1994 dataset on US SO_X and NO_X. Results are consistent with List and Gallet (1999): an EKC dynamics associated to a cubic specification is found for most specifications, though a sub sample analysis on 1984-1994 shows less significant results and the estimated turning points are very sensitive to the use of parametric or semi parametric specifications. Their work relies on the semi parametric flexible panel framework introduced by Schamalensee et al. (1998), who use world wide carbon emissions for the period 1950-1990, finding evidence of an inverse U relation with a within sample turning point for emission and energy use[14].

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[13] They also point out than for some pollutants, like CO_2, the lack of homogeneity is not a surprising outcome, given the trends in internationals specialisation, differences in local features and absence of strongly coordinated policies at least at international level. The issue of heterogeneity may thus be more or less relevant depending on the type of environmental issue under scrutiny (i.e. Waste vs emissions).

[14] They also use the model to project and forecast emission trends until 2050. An approach which attempts to forecast emission trends by using simulation techniques grounded on a dynamic growth oriented theoretical model is presented by Bratz and Kelly (2004), who finds evidence for EKC shapes, but with simulated turning points higher than that observed in the data and higher than the study state income. Smulders and Brteschger (2000) provide an analytical foundation for the claim that the rise and fall of pollution may be linked to policy induced technological shifts. See also Brock and Taylor, 2004, for an integration of the EKC framework into the Solow model of economic growth; their amended model generates an

Galeotti, Manera and Lanza (2006) and Galeotti, Lanza and Pauli (2006) present a quite skeptical view on EKC and test the robustness of EKC hypothesis, analysing CO_2 series. The first paper is aimed at checking the robustness of EKC on a more fundamental ground than the test for omitted variables, different periods, different parametric specifications. It addresses the very existence of the EKC dynamics on a statistical level, looking at the stationarity properties of the series; more specifically, they look at the cointegration properties of CO_2 time series by country. The data base is a panel of 24 OECD countries over 1960-2002. Tests conducted on cointegration through unit roots analysis of linear and log forms lead to mixed evidence when looking at the sample of countries. They thus conclude that, although unit root tests present some evidence in favour of the necessary stationarity, which provides economic and statistical meaningfulness to the EKC notion, further analysis is needed. The EKC still remains a fragile concept. We may affirm that, though it is true that many factors may effect results, from the set of variables included to the specification used in parametric and non parametric frameworks, the bulk of accumulated evidence may provide scope for a sound meta-analysis of main findings, which seem to point out that some new evidence is emerging supporting EKC dynamics for OCED countries, while the CO_2 dynamics of non OECD is far away from presenting plausible turning points[15].

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

Within the non-parametric arena, a recent paper is Azomahou et al. (2006), who use CO_2 data over 1960-1996 for 100 countries, exploiting non-parametric and parametric specifications for comparison. The paper also discusses the recent evidence within the semi and non-parametric literature, arguing that functional issue is more of a concern than the heterogeneity issue. They compare different models, finding that EKC shapes arise when a parametric panel model is used (signs positive for linear and squared terms, and negative for cubic term), but instead a monotonous relationship emerges from both non-parametric settings and first difference regressions, as in the semi parametric analysis of Bertinelli and Strobl (2005). This confirms that the non-parametric

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EKC relationship between both the flow of pollution emission and income per capita, and the stock of environmental quality and income per capita, with resulting EKC either inverted-U shaped or strictly declining.

Other theoretically based works, currently developing but still not many, are Andreoni and Levison (2001), who suggest that EKC dynamics may be technologically micro founded, and not strictly related to growth and externalities issues and Pasche (2002), who theoretically address the role of technological change in goods and production as a pre-requisite for an EKC sustainable evolutionary growth of the economy. Di Vita (2003) instead adds another underestimated argument, showing that the discount rate may play an important role in explaining for the income-pollution pattern observed. Low levels of income involve high values of discount rate, that are obstacles to the adoption of a pollution abatement policy. Only when the discount rate falls, as a consequence of growth, will it be possible to implement measures for emissions reduction, leading to an inverse U shaped income-pollution pattern.

[15] Cole (2003) also tackles this point, stressing that per capita emissions and income are typically non stationary and ECK regression do appear to not cointegrate. There may also be non stationary omitted variables. All these factors may lead to spurious representation of the income-environment relationship.

extension of the EKC literature casts further doubts on the hypothesis, though many recent works are mainly dealing with CO_2, which, among air emissions, is the most critical and ambiguous pollutant in terms of its dynamic link with economic growth determinants.

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

Liu (2005) estimates a simultaneous model, in which GDP and CO_2 are jointly determined, for 24 OECD countries over 1975-1990. In essence, he estimates both a revenue and an emission function. He shows that including per capita energy consumption in the emission regression, thus taking the structure of the economy into account, implies a negative link between income and CO_2, which is contrary to main findings and reverse the usual evidence emerging when omitting this factor. If we assume that energy consumption is more correlated to the structure of the economy instead that to income, it is worth studying the relationship between emission and income holding the structure fixed. This may change results and the interaction of EKC dynamics.

As far as sulphur emissions are concerned, Halkos (2003) exploits a large panel dataset consisting of 31 years (1960-1990) and 73 OECD and non OECD countries, applying random coefficients and Arellano Bond GMM method. In the latter model the EKC hypothesis is not rejected, with turning points between 2805-6230$/c. the study shows that such results are completely different from those obtained by using more usual fixed and random effects model.

A semi parametric approach is exploited by Roy and van Kooten (2004), who examine the relationship between income and three non point source pollutants: CO, ozone and NO_X (US 1990 data). Statistical tests reject quadratic parametric specification in favour of semi parametric model; data do not fit nevertheless with the inverted-U shaped hypothesis.

2.3.3 Spatial relationships, trade and development issues

Besides semi and non parametric approaches, value added may be found in extending the EKC model in various directions. Two relevant issues which has often been discussed in the literature concern the role of trade relationships and the (related) spatial network of links among the sample of countries.

Maddison (2005) uses a spatial econometric approach in order to test the hypothesis, for SO_2, CO, NMVOC and NO_X (1990 and 1995, for 135 countries), that national emissions are influenced by the emissions of neighbouring countries. The issue is of primary relevance for some emissions, while it is of minor importance for other areas, like waste. He shows that national emission for SO_2 and NO_X are heavily influenced by neighbouring countries emission flows[16]. This may be an explanation of why, when spatial lag is omitted, estimating EKC on geographically defined subsets results in evidence of parameter instability. OLS results show

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[16] We note that the method, as well as the analysis of bilateral trade relationship within the EKC framework, results highly expensive in terms of data losses, since eventual missing values undermines the setting up of necessary bilateral distances/trade relationships.

that for SO_2 it emerges a monotonic relationship with income, with elasticity of 0.47; participation to the Helsinki protocol is moderately significant, pointing to some policy effect on emissions. For NO_X, NMVOC and CO emissions are increasing over the range of income, with respectively a negative and a positive sign on linear and squared terms. Though elasticity values are affected, the signs and significances seem to not change much between OLS with and without spatial weights. In this case, only two out of four pollutants are associated to neighbouring countries effects.

Cole (2003, 2004) instead addresses the role of trade patterns, to analyse the extent to which EKC dynamics are possibly affected by changing trade dynamics complementary or as an alternative explanation of growth induced pollution abatement[17]. Trade patterns may mitigate the endogenous role of growth induced effects, or even changing the evidence, showing that trade flows and consequential "dumping" are determining the apparent, in this case, EKC evidence for more industrialised countries. The issue is clearly linked to the dynamics of trade patterns between more and less developed countries, influenced by a various factors such as different environmental policy stringency, changing comparative advantages, non homogeneous property rights definition on natural resources.

Some studies have tried from the beginning to include a variable of trade openness among the regressors. Nevertheless, such a variable has generated mixed evidence and it is probably not the best option to include trade patterns into the EKC picture. More specifically, trade openness may be associated to two possibly contrasting factors of comparative advantage: on the one hand the endowment effect, following the Hecsker Ohlin Samuelson model, should move pollution intensive industries from the south to the more capital intensive northern industrialised areas. On the other hand, the pollution have effect, also compatible with the HOS model, may act as an opposite force, with more polluting industries moving towards areas where property rights and policy enforcement is less stringent and the marginal costs of environmental degradation lower in economic terms. Cole (2003) introduces three elements: a trade intensity openness usual ratio, an interaction between trade intensity and country's capital-labour ratio, and an interaction between trade intensity and income. Main results, considering SO_2 and NO_X for 26 developed and developing countries over 1975-90, and CO_2 for 32 developed and developing countries over 1975-1995, are: evidence is robust across panel specifications; furthermore, the inclusion of trade and other covariates little affects the EKC evidence; finally the paper finds that the impact of trade elements on emissions is not highly significant. With the exception of SO_2, the full trade model does add little to EKC evidence, meaning that the turning points are not explained by the movement of economic activities towards less developed countries. Results are largely supportive of ECK dynamics. For SO_2, NO_X and CO_2 quadratic specifications show plausible and significant turning points, lowest for SO_2 (7-10000$) and highest for CO_2, at around 30-33000$. Cole (2004) marginally changes the specification, introducing a trade openness term as long as shares of polluting imports and exports, from and to non OECD countries, to test the pollution haven hypothesis. Quadratic and cubic specifications are analysed over 1980-1997 for a sample of OECD countries, concerning air and water emission indicators. Evidence is mixed: whereas EKC evidence is confirmed

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[17] The trade issue is also investigated by Rothman (1998) who favors a consumption based approach to EKC, which may be more relevant for some non emission related environmental issues, and suggests that consumers in rich countries may succeed in distancing from environmental problems by means of international trade. Trade may occur even within a country and its role may affect estimates if not considered (Aldy, 2006).

and only partially affected by trade related factors, the two export and import terms, though generally showing thee expected signs, do not arise as strongly significant.

Another work dealing with trade issues is Muradian et al. (2002), who estimate embodied pollution in trade for 18 industrialised economies with the rest of the world and with developing countries only, for the period 1976-1994. The balance of embodied emission in trade, calculated as embodied emissions in imports minus EE in exports, seems to support EKC shapes for Japan and Western EU, and an N shape for the US. In the period Japanese and European environmental terms of trade improved, while US terms deteriorated; that is EE in exports for the US has increased more than EE in imports over time. Though there is no statistical trend between income and EE in imports on a cross section basis, there seems to be a positive relationship at national level over time. This type of analysis may add some important insights and suggest further hypothesis for the EKC empirical literature.

To conclude on trade, Aldy (2005, 2006a,b) explores relationships among economic development, energy consumption and CO_2, using EIA data for US States over 1960-1999. He finds that the energy consumption income elasticity is positive but decreasing in income, though energy production takes an inverted-U shape, peaking at 21500$ reflecting energy imports for richer states. The standard CO_2 measure, corresponding to energy production, peaks and follows EKC dynamics, while when adjusting mission for inter states electricity trade, an N shape emerges. This is a key point: interstate electricity trade can affect estimated emission income relationship. The use of production based rather than consumption based statistics affect the estimation of EKCs curves, possibly yielding downward relationships which under estimate the real environmental impact. The carbon intensity of energy declines in income or total energy consumption and for industrial, residential and commercials sectors.

The trade issue has pointed emphasis to the dynamics of economic relationships between more and less industrialised countries. Turning attention to developing countries, it has emerged some new evidence concerning a rapidly growing country like China. One study is by De Groot et al. (2004), focusing on wastewater, solid waste and waste gas, over the period 1982-1997 for 30 regions. Estimating regressions in absolute and per capita terms with respect to regional GDP, they note that while for water pollution the trend is decreasing, an N shaped curve seems to emerge for solid and gas waste. Another work on China is by Meuniè (2004), who exploit data for the 30 Chinese regions, over 1990-1999, though limited in length, an interesting period of boosting economic growth and economy restructuring. Using a quadratic specification and some additional covariates like population density, to take into account of relevant urban related effects, heavy industry share, energy related factors to account for the effect of coal intensity of Chinese production of energy, he consistently finds for CO_2 a robust evidence in favour of EKC for China in all base and extended specifications, though peaks are quite sensible to the specification used, ranging from 2900 to 8500 Yuan (1995) per capita. Other controls, all significant, show expected signs: positive for heavy industry and for coal related energy, negative for population density (growth is higher where density is higher, this may capture joint effects).

Those studies are worth noting since they aforementioned and discussed point to the direction of using within country regional datasets, a point which was first raised by List and Gallet (1999).

In relation to the issue of developing countries and EKC, it is worth noting a promising line of research which tries to bring together the so called Resource Curse Hypothesis and the EKC framework. In essence, the first hypothesis is that countries with higher endowments of natural resources are experiencing lower economic growth, thus assessing the opposite link (environment → income) with respect to EKC studies. This integrated framework may also deal with the endogenous nature of the environment/income link, mentioned by some authors as a possible limitation of the EKC framework. Costantini and Monni (2006) and Costantini (2006) present empirical evidence concerning a cross country international dataset. The first study first analyses the effects of GDP, natural resource endowments, quality of institutions and globalisation on the economic growth over 1970-2003. The resource curse hypothesis is confirmed: countries with higher stocks of natural resources experienced lower growth rates, even controlling for another economic and socio-economic drivers. One explanation may be that large endowments crowds out the accumulation of human capital; the two forms of capital could be characterised by substitutability along the development scenario. Then they test the EKC hypothesis by specifying as dependant variable the genuine saving index provided by the World development report, which directly refers to the sustainability performance of an economy (available only for 1995 and 2000). They compare a standard EKC where CO_2 is the dependant variable and a modified EKC using the saving rate. The economic driver is GDP in the first model and a human development index included in both cases as "innovative" element of the analysis; quadratic and cubic specifications are used. Both analyses seem to confirm the Kuznets curve hypothesis. Referring also to Costantini (2006), the inclusion of a human development index into the usual CO_2 EKC regression shows a negative, plausible but weakly significant coefficient, while the same index provides a fully EKC dynamics when inserted as covariate into the genuine saving regression[18]. For studies that stress the relative higher importance, as explanatory variable, of income distribution (the dependant variable of the original Kuznets curve) rather than income per se, we refer to Torras and Boyce (1998) and Torras (2005a,b). The first paper assumes that a more equal income distribution, by enhancing the influence on policy of those who bear the costs of pollution, relative to the influence of those who benefit from pollution-generating activities, contributes to the EKC dynamics. An empirical analysis of international variations in seven indicators of air and water quality supports this hypothesis. Income distribution, literacy, political rights, and civil liberties are found to have particularly strong effects on environmental quality in low-income countries. The introduction of such variables sometimes weakens the pure income effect. Income distribution and other political and power and income distribution factors may play a role as environmental quality predictors in developing countries.

The other papers examine the effect of relative equality in the distribution of power on environmental outcomes, also making a clear distinction between health-related environmental outcomes and so called 'environmental amenities,' only the latter of which should be correlated strongly with income. A national index of power equality that is derived from related socioeconomic variables is introduced, and its effects assessed with respect to individual country achievement in addressing environmental quality and population health. Gangadarhan and Valenzuela (2001) also analyse the set of income-health-environment relationships, by

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[18] Costantini and Monni (2006) also identify a numerical measure of 'sustainable human development' by enlarging human development with more specific environmental aspects, thus building a complex Sustainable Human Development Index for European countries, given data availability. The composite SHDI has been calculated as the simple average of four development components, education attainment, social stability, sustainable access to resources, and environmental quality, and it may be the basis of new empirical research on the field, even replicable at a more disaggregated (regional) level.

adopting a two steps model, endogeneizing environmental quality. Income and environmental quality seem to be relevant drivers of health status along the development pattern.

Turning to specific evidence concerning western countries, Roca et al. (2001) present evidence on a fast growing economy like Spain using many emissions: CO_2, CH_4, SO_2, N_2O, NMVOC, NO_X. Regardless CO_2, whose data are available from 1973 to 1996 provided by IEA, data cover the period 1980-1996 (Ministry of the Environment). Time series analysis for Spain on the six pollutants show that only for SO_2 EKC evidence emerges. SO_2 confirms to be the most likely pollutant to be associated to EKC dynamics. For other emission, like CO_2, the base specification with income terms only is not significant, claiming the necessity of including other covariates. They use same energy related factors like coal and nuclear energy generation, and other sectoral related variables. All in all, the analysis does not show EKC evidence and for many pollutants, maybe given the limited length of time series, also lacks a statistical robustness to the regression. This points towards the exploitation of national databases which ground on regional or even provincial disaggregation, in order to provide more heterogeneity. This is the research line which we have indicated here as one of the most fruitful at the current status of research, and far as the issue of data quality and features is concerned, in addition to the value added that may arise from the use of more sophisticated and flexible econometric models.

Egli (2002) focuses on Germany, criticising the use of cross country datasets as Vollebergh et al. (2005) and other commented works. He finds that only for few pollutants a typical EKC pattern can be observed; all in all he argues that the foundations of EKC may be fragile. Using data for SO_2, NO_X, CO_2, PM, CO, NH_3, CH_4, NMVOC (essentially the NAMEA emissions indicators[19]) for the period 1966-1998, a time series estimation of a quadratic formulation with additional covariates such as reunification dummy, GDP industry share, imports-exports from pollution intensive production relatively to GDP, leads to the following (ambiguous) results: for nitrogen oxide and ammonia, an EKC shape is found with turning point of around 30000 DEM. For the other six pollutants clear outcomes do not emerge, astonishingly even for the evidence of a linear relationship between emission and income. The question if EKC is existing at the level of a single country is without answer. We may note that though time series analysis is valuable, within country heterogeneity, possibly exploitable in specific country panel datasets with a regional or productive desegregation, may provide a useful comparison for the assessment of the EKC hypothesis at country level. Interestingly, Egli stresses the importance of a somewhat neglected point, concerning data quality, quantity, and availability of a sufficient data heterogeneity. The literature has correctly emphasised methodological issues, but the data issue remains a core part. As long as with model mis-specifications, cross country analysis may be partially undermined by low data quality, at least for some environmental indicators. Value added may be found at national level, setting up time series or panel datasets, providing specific and heterogeneity based evidence relying on higher quality indicators which from the nineties can be largely available at least for OECD countries and for major environmental issues.

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[19] For a discussion on the macro economic relevancy of NAMEA indicators for delinking analysis, and some analysis grounded on Italian and Dutch data see Mazzanti, Montini and Zoboli (2007 forthcoming) and De Haan and Keuning (2000). The former paper presents a decomposition of emission and economic factors comparing Italy and the Rome region, the latter suggests what value NAMEA indicators may represent for empirical studies.

2.3.4 Some considerations about recent EKC literature

Despite the surveyed papers consider long time periods, on the geographical side the most part of them consider as elementary unit, the country (mainly an OECD country) and only in a few cases a within country desegregation is implemented (at US state level). Parametric and non parametric specifications are used and in several cases it has been showed that the evidence of inverted-U shaped curve depends on the econometric method used and is quite sensitive to the degree of heterogeneity included in the panel estimations. The recent literature casts doubt on the foundations of EKC results, and stresses their contingency on the empirical model and specifications used.

We may sum up the surveyed papers by saying that three (different) value added may be found in estimating (i) panel with slope and intercept heterogeneity, which, as noted by Baltagi et al. (2002) are nevertheless not the panacea; (ii) single country panel dataset where within country heterogeneity is exploited; (iii) specific time series at national or state/regional level, provided data availability on sufficiently long time series. We argue that (ii) and (iii) are the most promising fields of research where future empirical efforts may be intensified, with the help of newly constructed, more heterogeneous and longer datasets at country level or for samples of countries in homogenous relevant areas, instead of cross country international datasets which may hide very different stories (Brock and Taylor, 2004).

Our survey was instrumental to draw out what the main line of current research are in the EKC literature. The recent literature casts doubt on the foundations of EKC results, and stresses their contingency on the empirical model and specifications used. Though this is an issue which needs further research, we claim that national based studies which exploit a rich source of within country heterogeneity and tests the robustness of results within the boundaries of panel parametric specifications[20] provides value added and food for policy, given sufficient time series length, relevancy of the period under scrutiny, cross section heterogeneity and the analysis of different specifications. Most flaws may be solved or mitigated by increasing the quantity and quality of data, carrying out sound country specific analysis.

3. Data and methodology

The contribution of our empirical exercise is twofold: first, we assess EKC shapes for NAMEA emissions in a single country, Italy, rather than taking a cross country perspective, by using panel disaggregated data at both sectoral and provincial level. We argue that the exploitation of disaggregated data is another way of improving the understanding of income–environment relationship, providing a natural ground rich of heterogeneity, in addition to recent studies which try to improve the statistical evidence stemming from cross country datasets using econometric techniques which deal with heterogeneity (Martinez Zarzoso et al., 2004; 2006; Mazzanti, Musolesi and Zoboli, 2006).

Secondly, given a sufficiently extended dataset, we also analyse the EKC shapes on manufacturing and services branches separately, in order to check whether the average picture differ from the sub sample analyses. The exploitation of sub samples analysis has been suggested from a conceptual perspective, specifically on

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[20] The parametric analysis presents costs but also benefits, with respect to semi or non parametric investigations; the latter do not fully outperform by definition parametric models (Greene, 1997, p.904).

NAMEA[21] data (Femia and Panfili, 2005) and it has been carried out in recent works, proving to be an effective way, for example, focusing on different geographical areas (Martinez Zarzoso et al., 2004; 2006; Mazzanti, Musolesi and Zoboli, 2006). As far as our work is concerned, and generally for industrialised countries, from both an economic and policy point of view it is interesting to see whether the income-environment EKC dynamics of the decreasing (in GDP share) manufacturing sector (but more intense in emissions generation), and the increasing (in GDP) service sector (but less intense in emissions generation), differ.

Finally, to our knowledge this is one of the first studies, if not the first, to test the EKC hypothesis on a developed country by exploiting a panel matrix of emissions and value added data regarding 29 main economic production branches, from agricultural to manufacturing and services. This is an alternative way of proceeding for the analysis of national EKC specificity, with respect to, for example, time series studies which investigate the structural changes of the economy over the long run (Lindmark, 2002).

3.1 The dataset: sources and value added

The source mainly used for the sectors-pollutants dataset implementation is the National Accounts Matrix including Environmental Accounts (NAMEA) recently published by ISTAT. The first NAMEA, referred to 1990 data, was published in ISTAT (2001) and then in the following years several other NAMEA have been published up to the year 2002. Nine air pollutants[22] are considered by NAMEA data and they refer to emissions from several economic activities that we have recoded by using 29 productive branches (2 in the agricultural sector, 18 in the industrial sector, 9 in the services' sector including public administration) over 1990-2001 (see tables 2a and 2b for the branches specification and some descriptive statistics). Other data about the national value added and the units of labour (full time equivalent jobs) are included in the NAMEA[23].

The air emissions data collected in the provincial dataset are drawn from the SINAnet-APAT database[24] that contains information for 21 pollutants and three years 1990, 1995 and 2000[25]. Among those 21 pollutants, we have chosen the same 9 considered in the national level dataset (sectors-pollutants).

Our processing on ISTAT data have been done to obtain the 1990 per capita value added at 1995 prices comparable with respect to the ISTAT 1995 and 2000 value added data. ISTAT is the source for the population and territory surface data too.

The dataset contains information related to the 95 Italian provinces existing before the introduction of 8 new provinces happened in 1995. This fact has created some dataset implementation problems; the 1995 and 2000 ISTAT value added data contain the 8 new provinces too, while the APAT emission data contain the new

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[21] See the works by Ike (1999), Vaze (1999), Haan and Keuning (2000) and Keuning et al. (1999), among the others, who provide descriptive and methodological insights on NAMEA for some major countries.

[22] The pollutants considered in NAMEA are only air pollutants: Carbon dioxide (CO_2), Nitrous oxide (N_2O), Methane (CH_4), Nitrogen oxides (NO_x), Sulphur oxides (SO_x), Ammonia nitrogen (NH_3), Non methane volatile organic compounds (NMVOC), Carbon monoxide (CO) and Particulates matter (PM10). Lead (Pb) emissions have been excluded from the analysis.

[23] We are not aware of any other EKC analysis carried out on NAMEA datasets, which provide rich information at the level of sector branches on economic and environmental sides.

[24] The air emissions derives from more than 300 human and biogenic activities and are estimated according to the CORINAIR methodology.

[25] Unfortunately, the provincial emission are estimated only every 5 years.

provinces only from the year 2000. This is the reason why we have chosen the Italian provincial subdivision that existed before the 1995[26].

For the 7 provinces from which the 8 new ones have been derived in the 1995, the 1995 and 2000 value added data have been calculated with a weighted average for the resident population in the sub-provinces. Also the population for the same 7 provinces have been obtained with the sum of the population resident in the sub-provinces. Finally the 2000 emission data available for the 8 new provinces too have been added to the old provinces emission to have full comparability with the 1990 and 1995 data.

3.2 Methodological issues and the empirical model

The first methodological problem for the applied analysis is how to specify the EKC functional relationship. There is no consensus on this point. Some authors adopt second order polynomial, others have estimated third and even forth order polynomials, comparing different specifications for relative robustness. It is worth noting that neither the quadratic nor cubic function can be considered a full realistic representation of the income-environment relationship. The cubic implies that environmental degradation will tend to plus or minus infinity as income increases, the quadratic implies that environmental degradation could eventually tend to zero. Third or fourth level polynomial could also lead to N rather than U shaped curves, opening new problematic issues in understanding the income-environment phenomenon for policymaking. The N shape is justified by a non-linear effect by the scale of economic activity on the environment, which is difficulty to prove[27]. Finally, the use of the income factor only, without quadratic and cubic terms, would collapse the EKC analysis to the basic decoupling analysis.

We here test the hypothesis by specifying a proper reduced form usual in the EKC field (Stern, 2004):

(1) $\log(\text{Emission/employees}^{28}) = \beta_{0i} + \alpha_t + \beta_1 \text{Log}(\text{Value added/employees})_{it} + \beta_2 \text{Log}(\text{Value added/employees})^2_{it} + \beta_3 \text{Log}(\text{Value added/employees})^3_{it} + e_{it}$

where the first two terms are intercept parameters, which vary across sectors and years.

Thus, for each combination of the dependant and independent variable listed above, different specifications are estimated, including: the linear regressors only (delinking baseline case), linear and squared terms (EKC most usual case), and finally a specification with linear, squared and cubic terms. Given the panel data framework, the relative fit of fixed effect and random effect models is compared by the Hausman statistic. We also test the presence of first order serial correlation[29], AR (1); in case, we verify whether this affects significantly estimates.

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[26] In the other case – by considering the 103 provinces - we cannot use the 1990 and 1995 SINAnet-APAT data or we had to restrict our analysis to the 88 provinces not involved by the administrative changes.

[27] Shobee (2004) suggests a third order polynomial specification as more realistic relationship between environmental degradation and income per capita.

[28] Employees are substituted by the population of the province in the provincial based analysis.

[29] Following the procedure in Wooldridge (2002, p.176), which tests serial first order correlation by a t test on the coefficient of the lagged fitted residual term in a regression which sees as dependant variable the fitted residual in time T and the vector of explanatory factors. Lagged residuals are significant in both FEM and REM models, thus the correction model, which does not consider time T for estimation, is indicated. As noted by Wooldridge (2002, p.176), one interpretation of serial correlation in the errors of a panel data model is that the error in each time period contains a time constant omitted factor.

Table 3 presents estimated regression for each pollutant. We show only results associated to the best fitting specification for each emission, in terms both of FEM/REM models, autocorrelation and polynomial specification. We refer the reader to notes under table 3 for further detailed comments.

4. Empirical outcomes

4.1 EKC for NAMEA emissions: All sectors empirical evidence

We test the EKC hypothesis for nine different emissions (see par. 3). We specify a logarithmic model as base case, but we also use as term of comparison and of external validity the estimation of a non logarithmic model. In most cases, the fixed effect specification[30] is preferred by the Hausman test, though we do not highlight any significant difference between the two models in the few cases the test is favoring the REM.

An EKC shape is found for CO_2, CH_4, NH_3 and CO. CO_2 and CH_4 outcomes are similar with and without time effects, while the CO regressions are significant only when including time period effects and in AR1 specification. Turning points (TPs) are, for CO_2, CH_4, NH_3 and CO, robustly within the range, though for CO are quite polarized in different estimates (table 2).

Other emissions present the following evidence. N_2O is associated to a positive linear effect (with elasticity 0.485); the squared specification leads to EKC but the TP is outside the range. An N cubic shape is observed for SO_x and NO_x, though the latter also presents a significant quadratic specification. This is interesting since those two emissions are the one most likely indicated by the literature to present EKC dynamics across different countries. It seems here that the EKC dynamic is present, but it is currently being reversed by a new positive effect of income on the environmental emission, occurring as income increases. The inverted-U shape turns into an N shape, representing the problem of a positive elasticity with respect to high levels of income. This also confirms recent evidence on this two leading indicators. Similar evidence is also found for PM10 and NMVOC.

Non logarithmic regressions confirm the EKC dynamic for CO_2 and CH_4. In this framework, also N_2O and NMVOC present EKC. NO_X and SO_X present linear and squared terms respectively with negative and positive signs; nevertheless, this outcome is consistent with the N shape observed above: as income grows toward very high levels, the eventual turning point occurring at lower income levels is being turned over a new path of growing emissions with respect to income.

Serial correlation may be verified by a test on the residuals (Wooldridge, 2002, p.176). If the null hypothesis of no correlation is not rejected, the model is definable as dynamically complete in the conditional mean. In any case, the loss of efficiency in presence of correlation, in models that involve relatively slowly changing variables, like consumption and output, is not so severe (Greene, 1997, p.589-590). In addition, we note that if the stationarity assumption holds, autocorrelation fades over time, but correlation have to be dealt with since it may cause more or less severe losses of efficiency.

We recall that the corrected correlation model reduces the number of observations since it is based on T-1 periods, unlike the time period effect model.

[30] We estimate the EKC model by NLogit 3.0, using a least square dummy variable specification (LSDV), fixed effect (FE). The Hausman tests generally provides evidence in favour of the FE model, nevertheless, results do not differ sharply when the random effect model is estimated. We use a LSDV model since we are not specifically interested in estimating individual fixed effects, which may be inconsistently estimated when N increases. On the other hand, the alternative within effect model does not present an intercept. Since no dummy is used, this model has a larger degree of freedom for error, resulting in incorrect (smaller) standard errors for the parameter of interest. As a reference see Wooldridge (2002).

The empirical evidence concerning NMVOC is less conclusive, since while a negative linear specification emerges with the higher fit without time dummies (the squared term is weakly significant), introducing period effects change the shape into a EKC quadratic specification.

Finally, NH_3 is here associated to an N shape instead of EKC evidence, while PM10 and CO do not lead to significant regression as far as the overall significance is concerned.

Thus, the comparison of (i) baseline LSDV with models including time effects and (ii) logarithmic and non logarithmic models highlights that EKC outcomes may be dependant on the chosen specification. Nevertheless, we underline that the logarithmic specifications are to be preferred for the nature of data, since the help smoothing the environmental and economic trends. In any case, though non logarithmic models change some results, they do not sharply affect the structural conclusions we draw on the basis of logarithmic specifications. Logarithmic specifications show that most emissions are associated with EKC trends (four-five out of nine, including CO_2 and CH_4), three case are critical since N shapes are observed for key environmental pressures, and in one case a linear positive relationship emerges (N_2O)[31].

It is worth noting as a final point that we tested the influence of sector dynamics by including dummies for services, manufacturing and other industries; those variables arise generally not significant. Thus, though the dataset shrinks, we provide specific evidence for three sub samples of NAMEA.

4.2 Disaggregated evidence for industry, services and manufacturing

Further empirical analysis may be focused on the disentangled branches. The benefit is that we may observe potential differentiated dynamics concerning the productivities link, between services and manufacturing. The current cost we face is a lower statistical robustness due to data losses when splitting the full dataset. Given that, we estimate only base specifications (without AR1 corrections).

Table 4 presents a summary of empirical evidence differentiating between services (E-O), Industry (C-F) and manufacturing industry only (D)[32]. We provide comments for main results. More detailed outcomes are available upon request.

Summing up, the analysis on disentangled economic branches highlights that the EKC pattern is influenced by different sectoral dynamics. It adds information to descriptive findings. For example, commenting NAMEA data Femia and Panfili (2005) observe that service activities are more efficient from an environmental point of view, though not as much as one could have expected. The reason may be that those sectors induce matter transformation even if the "product" is not directly material.

The evidence is quite heterogeneous across emissions. In previous aggregate analysis, five out of nine emissions emerged associated to an EKC dynamics, while three showed signs of N shapes. Let us analyse what the driving forces of those trends may be at sectoral level. Within the former group of emissions, CO_2 trend appears driven

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[31] Table 2 also shows the estimates using the value of production instead of value added. The correlation between value added and the value of production is 0,72. The arising evidence is for an inverted-N shape in six cases and N shape for three. Cubic specifications appear to perform better. Value added is in our opinion the most proper independent income variable in this EKC analysis.

[32] See Femia and Panfili (2005) for a descriptive analysis of eco efficiency (emission on value added) on different sectors, by using NAMEA 1995 and 2000 datasets. See also Mazzanti, Montini and Zoboli (2007 forthcoming) for a shift share analysis of eco efficiency comparing 2000 data for Italy and the Lazio Region.

by all three sectors though industry/manufacturing, differently from services, are likely to present again a positive elasticity for high values, signalling a critical point. CO presents a similar picture. CH_4 disaggregated evidence confirms that the EKC aggregate picture is driven by all three macro sectors.

N_2O could be considered an outlier. The EKC turning point was outside the observed range above. The sectoral analysis shows a weak evidence for N shapes in industry and manufacturing; in any case agriculture is not considered because of data paucity. This may represent a flaw since it is the main driving sector. The same applies to NH_3, which, nevertheless, shows a leading role played by manufacturing in explaining the aggregated EKC evidence.

Within the emissions which were showing N shapes at aggregate level, we note that for trans boundary ones like NO_x and SO_x, services are associated to a negative trend, though the effect of industrial sectors is likely to overwhelm it. SO_x particularly show U shapes, which were also observed at aggregate level. Oppositely, PM10 N shape is driven by all sectors, with services associated to a positive relationship here, and industry showing some signs of inverted-U. Finally, NMVOC mixed evidence is explained by an N shape for manufacturing balanced by inverted-N shapes linked to services and industry.

Summing up, the sectoral analysis has highlighted that aggregate outcomes should hide some EKC heterogeneity across different sectors. Services tend to present inverted-N shapes in most cases. Manufacturing shows a mix of EKC inverted-U and N shapes, which highlight criticalities. The same is true for industry: though a turning point has been experienced, N shapes may lead to new increase of emissions with respect to high levels of the income driver.

4.3 NAMEA emissions: an analysis with provincial data (1990-2000)

The evidence arising from a dataset disaggregated in geographical units is important since it complements previous analyses, whose evidence (in favor or not) of a delinking is based on emissions and income trends associated to the value added of industrial and services activities, but omitting, for example, the "household" sector role (in energy consumption) and the private transport effect on emissions. The observed trends could thus differ. In this case, a critical reasoning arises around the relative role played by core economic activities and the economic system as a whole in shaping the dynamic relationship between environmental pressure and economic growth.

With provincial data, the analysis shows mixed evidence in support of the EKC hypothesis (tables 5a and 5b)[33]. Inverted-U shaped curves, for the three-years period (1990, 1995, 2000) here considered, arise for some of the pollutants in the SINAnet-APAT provincial database, like CH_4, NMVOC, CO and PM10 (but in the NMVOC and CO cases the cubic specification shows an inverted-N shape), with coherent within range turning points

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[33] Within the field of country based analysis exploiting geographical data, we note Lantz and Feng (2006) who analyse a five region-30 years panel dataset for Canada, finding that carbon emissions depend on and show EKC patterns with respect to population and technology, while GDP per capita seems surprisingly unrelated to CO_2. This confirms the view that the validity of the EKC hypothesis (in addition to diversities arising from the use of different econometric models) is strictly reliant on an extended set of factors: the temporal period, the country, the emission, the considered sector, and also the geographical/economic dis-aggregation of reference (geographical unit). This is to say that the EKC hypothesis refers to multi faceted empirical evidence, where many EKCs eventually exist. The possible emergence of different shaped EKCs as well as other complex configurations of the growth-emissions relationship, and the country/region specificity of EKCs as resulting from our analysis, should warn about the non-deterministic nature of the processes behind EKC.

despite quite low (from 8,200 to 12,100€). Nevertheless, other emission trends show a monotonic relationship (CO_2 and N_2O), or in some cases an inverted-N shaped relationship (SO_x and NO_x)[34]. NH_3 emissions show evidence of EKC partially, with an inverted-U shape significant in the non logarithmic specifications only.

5. Conclusions

This paper provides new empirical evidence on delinking trends concerning emission-related indicators in Italy. The main value added of the paper is that it provides EKC evidence exploiting environmental-economic merged panel datasets at decentralized level, making use of a long times series and rich cross section heterogeneity both at sectoral and Provincial level.

The evidence arising from such investigations is, in our opinion, more informative than cross country evidence, predominant way of analysis in the EKC literature. Other ongoing research directions surveyed in section 2 are valuable. We here focus on the necessity of exploiting EKC trends by means of within country disaggregated data. This directly interests the European debate over the implementation of environmental policies. At the current state, most policies are implemented by setting homogeneous targets across countries, leaving some space for a different use in policy instruments. Similar targets are more coherent with the hypothesis that the trend characterizing object countries in terms of environment-growth relationship is more or less the same. Instead, if national studies should confirm, as it is emerging from more in depth analysis of heterogeneity in recent cross country panel investigations, that trends differ concerning both/or the elasticity and/or the eventual turning points, the argument in favour of a (full or partial) differentiation also for national targets would be strengthened.

We find mixed evidence in support of the EKC hypothesis. Inverted-U shaped curves for the period here considered arise for some of the pollutants in the matrix NAMEA, like CO_2, CH_4 and CO, with coherent within range turning point. Nevertheless, other emission trends show a monotonic relationship, or in some cases an N shaped relationship (SO_x, NO_x, PM10). Other emissions show relatively less robust results, with mixed evidence arising from different specifications. This partially confirms some of the criticism on the EKC empirical investigation that has recently mounted. Nevertheless, our analysis shows that probably the key point is that it does not exist an EKC dynamic, but many EKC dynamics, differing by (i) period of observation; (ii) country/area; (iii) emissions/environmental pressures; (iii) sectors. The key fact which should inspire future analyses is that not only EKC dynamics are specific to a country or a region, but even, within a country, to sectors and sub geographical areas. The degree of (technological) development is highly differentiated by sectors and geographical entities. In fact, a sectoral disaggregated analysis highlights that aggregate outcome should hide some heterogeneity across different sectors. Services tend to present inverted-N shapes in most cases. Manufacturing shows a mix of EKC inverted-U and N shapes, which highlight criticalities. The same is true for industry: though a turning point has been experienced, N shapes may lead to new future increase of emissions with respect to the income driver.

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[34] Comparing outcomes in par 4.1 and 4.2, we may induce that EKC trends for CO_2 are driven by production activities, while household economic activities tend to show monotonous relationship (that explain the evidence when accounting all national emissions). The opposite is valid for SO_x and NO_x.

Also the evidence arising from the provincial dataset shows mixed evidence in support of the EKC hypothesis. Four pollutants (CH_4, NMVOC, CO and PM10) show inverted-U shaped curves with coherent within range turning points. Other emission trends show a monotonic relationship (CO_2 and N_2O), or in some cases an inverted-N shaped relationship (SO_x and NO_x). NH_3 emissions show evidence of EKC partially, with an inverted-U shape significant in the non logarithmic specifications only. The two analyses are not directly comparable, though being on the same temporal period. The differences in results could be attributable either to the different datasets, the sectoral NAMEA being "embedded" as far as emission amounts are concerned, in the total national APAT dataset, or to the longer time period observations present in the sectoral one. Thus, the stronger and more robust evidence in support of an inverted-U shape for most pollutants may be partly due to a higher role played by main productive activities with respect to the household sector and private transport, and partly to the structure (length and width) of the two panel datasets. Further investigations are needed in the next future.

Following our investigation, we suggest to focus future applied research on other national studies, grounded on geographical heterogeneity, instead of cross country analysis, and to focus on sectoral trends, which are more informative for economic and policy implications. Cross country study at regional level (e.g. $EU_{15/25}$, US, etc.) may be useful when studying the relative effectiveness of heterogeneous policy efforts across countries which are homogenous regarding other structural features. The robust implementation of investigations disaggregated by sectors and geographical units nevertheless needs large datasets. We thus point to the need of spending increasing and constant efforts in the construction of integrated environmental / economic statistical accounts at national level, by intensifying the effort towards disaggregated data collection at sectoral and geographical level. The value of both cross section and time series heterogeneity has to be recognised.

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Table 1 – Recent EKC literature survey

Author(s), (publication year)	Methodological issues (model/estimation technique)	Countries/ geographical focus	Time period	Emissions	Material flows	Waste	EKC Evidence	Turning point	Note/considerations
Auci and Becchetti, (2005)	Parametric specification	197 countries WDI dataset	1960-2001	CO_2	No	No	Inverted-U shape	Above mean income level	CO_2 per unit GDP instead of CO_2 per capita
Azomahou et al. (2006)	Non parametric and parametric specifications	100 countries	1960-1996	CO_2	No	No	The non parametric extension of the EKC literature casts further doubts on the hypothesis		In their opinion the functional issue is more of a concern than the heterogeneity issue
Carson et al., (1997)		US state level data					Decrease for 7 major pollutants with respect to per capita income		
Cole, (2005)	Slope heterogeneity within a random coefficient model	110 OECD countries NO_x: 26 countries	1984-2000 NO_x: 1975,1980,1985,1990	SO_2, CO_2 and NO_x	No	No	SO_2, inverted-U shape. Evidence for NO_x is different across samples. CO_2, inverted-U for the OECD only sample.	FE estimation full sample: SO_2, about 16.000 1995 US$; NO_x, about 152.000 1995 US$.	
De Bruyn et al., (1998)									Criticism on panel data estimation
Diikgraaf and Vollebergh, (2005)	Time series analysis compared to heterogeneous panel estimations	24 OECD countries	1960-1997	CO_2	No	No	Inverted-U shape	14.000-15.000; 20.600$ with slope homogeneity	
Fisher, Kowalski and Amann, (2001)		Richest OECD countries		Yes	Yes	Yes			
Galeotti, Lanza and Pauli (2006)	Weibull function	Countries of the UN framework Convention on Climate Change	1960-1998 (1971-1998 all other countries in the IEA 2000 dataset)	CO_2	No	No	Around 16000€ for OECD countries; between 16.000 and 20.000 for non OECD countries	Inverted-U shaped curve for OECD countries	Data sources seem to not affect EKC evidence (in the OECD countries case)
Galeotti, Manera and Lanza (2006)		24 OECD countries	1960-2002	CO_2	No	No		EKC dynamics for OECD countries; non OECD countries far away from presenting plausible turning points	EKC considered a fragile concept

Table 1 – Recent EKC literature survey

Author(s), (publication year)	Methodological issues (model/estimation technique)	Countries/ geographical focus	Time period	Emissions	Material flows	Waste	EKC Evidence	Turning point	Note/considerations
Halkos (2003)	Random coefficients and Arellano Bond GMM method	73 OECD and non OECD countries	1960-1990	SO_x	No	No	EKC not rejected in the Arellano Bond GMM method estimation	2805-6230 in the Arellano Bond GMM method estimation	Even when data for a large number of developing countries are used the magnitude of TPs dependes on the econometric method used
Harbaugh et al. (2002)		Countries and cities world wide					Little empirical support for an inverted U-shaped relationship		Demonstrate the lack of robustness of EKC when countries, variables and intervals are changed
List and Gallet, (1999)	SUR estimation	US state level data	1929-1994	SO_2 and NO_x	No	No	Inverted-U shape	NO_x 8000-17000$; SO_2 15000-20000$ ($1987)	
Liu (2005)	Simultaneous model	24 OECD countries	1975-1990	CO_2	No	No			
Martinez, Zarzoso and Morancho, (2004)	Panel data; slope heterogeneity	22 OECD countries	1975-1998	CO_2	No	No	N shape majority OECD countries; inverted-U shape less developed countries	Cubic specifications: 1577-32009 Sq-specifications: 4914-18364	
Millimet et al. (2003)	Parametric and semiparametric model	US state level data	1929-1994	SO_x and NO_x	No	No			The paper shows the higher robustness of semi parametric models with respect to traditional panel structures
Roy and van Kooten (2004)	Semiparametric model	US	1990	CO, ozone and NO_x	No	No	The results do not support the inverted-U hypothesis		Statistical tests reject quadratic parametric specification in favour of semi parametric model
Schmalensee et al., (1998)		World wide	1950-1990	Carbon emissions	No	No	Inverted-U shape	Within sample	
Taskin and Zaim (2000)	Kernel and parametric estimations	52 countries	1975-1990				N shape	5000-12.000 per capita	
Vollebergh et al., (2005)	Parametric and non parametric specifications	24 OECD countries	1960-2000	CO_2	No	No	Inverted-U shape exists for many but not for all countries		Inverted-U shaped curve is quite sensitive to the degree of heterogeneity included in the panel estimations.

Table 2a. Sector branches description

Sector Code	Sector Description
A	Agriculture
B	Fishery
CA	Extraction of energy Minerals
CB	Extraction of non energy Minerals
E	Energy production (electricity, water, gas)
F	Construction
Manufacturing industries (D)	
DA	Food and beverages
DB	textile
DC	Leather textile
DD	Wood
DE	Paper and cardboard
DF	Coke, oil refinery, nuclear disposal
DG	chemical
DH	Plastic and rubber
DI	Non metallurgic minerals
DJ	Metallurgic
DK	Machinery
DL	Electronic and optical machinery
DM	Transport Vehicles production
DN	Other manufacturing industries
(Services)	
G	Commerce
H	Hotels and restaurants
I	Transport
J	Finance and insurance
K	Other market services (Real estate, ICT, R&D)
L	Public administration
M	Education
N	Health
O	Other public services

Table2b. Emissions and value added (yearly values): descriptive statistics

Variable	Mean	min	max
VA/N	53,10	10,77 (B, 1992)	286,70 (CA, 1997)
CO_2/N	65176,48	460,1751 (M, 1990)	1402528, 39 (E, 2002)
CH_4/N	150,9765	0,057327 (M, 2002)	2532,667 (CA, 1990)
N_2O/N	8,78358	0,033108 (M, 1990)	121,7485 (DG, 2001)
NO_x/N	148,5734	1,256879 (M, 2002)	3051,222 (E, 1991)
SO_x/N	308,1429	0,16914 (M, 2002)	6406,314 (E, 1990)
NH_3/N	11,29025	0,001477 (M, 1990)	325,1738 (A, 2002)
NMVOC/N	155,3243	0,280438 (M, 2002)	2893,252 (DF, 1992)
CO/N	118,7348	1,445866 (M, 2002)	796,8578 (E, 1990)
PM_{10}/N	19,88375	0,09783 (M, 2002)	290,3656 (E, 1990)

N=employees (thousands); VA=value added (Millions of euro liras 1995); Emissions (tons)

Table 3. Empirical evidence: testing the EKC hypothesis for sectoral emissions (sectors A-O, years 1990-2001)

	CO_2/N	N_2O/N	CH_4/N	NO_x/N	SO_x/N	NH_3/N	NMVOC/N	CO/N	PM10/N
VA/N	1,342***	1,576***	2,55***	5,44***	21.06**	8,251***	9,02*	11,024***	8,05***
(VA/N)2	-0,147***	-0,1051**	-0,263***	-1,31**	-6,74***	-0,860***	-2,581**	-3,056***	-1,840***
(VA/N)3	/	/	See comment	0,103*	0,618***	/	0,228**	/	0,138***
FEM/REM	REM	REM	FEM	FEM	FEM	FEM	FEM	FEM	FEM
Time fixed effects	Same EKC pattern	Linear specification, 0,485***	Same EKC pattern	Not significant	Very low significance of coefficients (*)	Not significant	EKC	Same EKC pattern	EKC
AR1	Yes	No	No	Yes	Yes)	Yes	Yes	Yes	No
Non logarithmic specification	Same EKC pattern	Same EKC pattern	EKC	Delinking (--10,544***, +0,0229***) does not emerge also in the squared, though the preferred AR specification is not significant in this case	Same N shaped pattern, less significant coefficients	Not significant	Delinking does not emerge also in the squared specification	Inverted-N shape	Not significant (cubic)
comment	EKC evidence	EKC evidence	EKC evidence: EKC and inverted-N both significant	Mixed evidence: quadratic and cubic forms both significant; N shape	N shape; both quadratic (-, +) and cubic forms signal a positive relationship after a TP	EKC evidence	Mixed evidence (EKC but TP outside the range; no delinking and N shape in other models)	AR1 and time period LSDV models are leading to EKC: TPs are very different	EKC emerging, but evidence for N shape also
Turning point(s) (VA/N)	90,6-140,5	*1803,47*	127,47-178,3	92,29 (squared)	/	120,48	*658,04* (Time period effects)	6,08-178,21	109,54-161,00 (squared)
VA/N range	10,77-286,7 (mean 52,86)								
F test and Chi squared prob.	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
N	377	377	377	377	377	377	377	377	377

Notes: Coefficients are shown in cells: *10% significance, **5%, ***1%. For each column we present the best fitting specification (linear, quadratic, cubic) in terms of overall and coefficient significance. Random or fixed effect specifications are presented accordingly to the Hausman test result. The FE model estimated is a LSDV model; individual fixed effect coefficients are not shown. According to the AR (1) test, the estimates refer to an AR corrected model when indicated by the AR1 test (null hp: no serial correlation); "no" in the AR1 row if otherwise. Turning points shown are estimated for logarithmic specifications.

Table 4. Empirical evidence: testing the EKC hypothesis for NAMEA emissions (services, manufacturing, industry, years 1990-2001)

	CO_2/N	N_2O/N	CH_4/N	NO_x/N	SO_x/N	NH_3/N	NMVOC/N	CO/N	PM10/N
Services N=108 (12 years*9 sectors)	Inverted-N shape	Not significant coefficients	Linear relationship	Inverted-N shape	Inverted-N shape	N shape	Inverted-N shape	Inverted-N shape	U shape
VA/N	-73,00***		-1,82***	-138,27***	-503,73***	324,35**	-276,4**	-313,16**	-9,68***
(VA/N)2	18,21***			33,91***	123,77***	-79,84**	67,65**	75,94**	1,11***
(VA/N)3	-1,50***			-2,76***	-10,11***	6,54**	-5,53*	-6,16**	
VA/N turning points	A negative relationship is generally observed over the period								
VA/N: mean 44,08; range 24,7-98,18									
Manufacturing N=168 (12*14)	N shape	N shape (weak)	Inverted-U shape	N shape	U shape (quadratic); N shape	Inverted-U shape	U shape (quadratic); N shape	Inverted-U shape	N shape
VA/N	20,32***	15,23**	6,104***	32,75***	46,71**	39,08***	12,38**	4,428***	28,23***
(VA/N)2	-4,41***	-3,07**	-0,587***	-7,72***	-14,52***	-4,10***	-3,36***	-0,467***	-6,75***
(VA/N)3	0,311***	0,210*		0,599***	3,22***		0,293***		0,531***
VA/N turning points	86,09 (quadratic)	201,23 (quadratic)	181,14	397,20 (quadratic)		116,29		113,56	
VA/N: mean 47,15; range 21,61-203,84									
Industry N=216 (12*18)	N shape	N shape (weak)	Inverted-U shape	N shape	U shape	N shape	Inverted-N shape	N shape	N shape
VA/N	12,96***	12,81***	6,86***	27,38***	-18,06***	115,61***	-17,99***	17,24***	19,64***
(VA/N)2	-2,86***	-2,506***	-0,696**	-6,197***	1,75***	-23,68***	4,27***	-3,65***	-4,44***
(VA/N)3	0,207***	0,168*		0,457***		1,61***	-0,324***	2,56**	0,328***
VA/N turning points	137,07 (quadratic)	281,57 (quadratic)	138,12	119,56 (quadratic)		156,15 (quadratic)		150,36 (quadratic)	136,02 (quadratic)
VA/N: mean 61,34; range 21,61-286,7									
comment	Aggregate EKC dynamic appears mostly driven by services: other sectors could overall be experiencing a decrease in emissions, though a new increasing trend is likely to occur	Weak N shape emerging; overall the aggregate EKC dynamic appears driven by industry and manufacturing which show TP around the highest VA level of the range§	Aggregate decoupling/ EKC dynamic appears driven by all three sectors§	Aggregate N shape is confirmed in industry and manufacturing, though services experience a negative relationship	Aggregate N shape may be the mix of U and N shapes industry and manufacturing, though services experience a negative relationship	The aggregate EKC evidence appears driven by manufacturing more than others which tend to show N shapes§	The aggregate no delinking and N shaped evidence appears driven by manufacturing while other sectors present a negative link. Manufacturing is a major emitter.	The aggregate EKC evidence appears driven by services and manufacturing, while industry is associated to a likely new increase after experiencing a TP	The N shape on aggregate is driven by industry and manufacturing; services even present an increasing trend without TP

Notes: results shown are related to log specifications. Value added turning points estimated for inverted-U shapes. AR and time period LSDV models generally not estimated given the reduced availability of data in sub samples (reduced degrees of freedom).

§ agriculture though relevant is not estimated due to data paucity.

Table 5a. Empirical evidence: testing the EKC hypothesis for APAT emissions (logarithmic specifications, years 1990, 1995, 2000; N=285, 3 years*95 provinces)

	CO_2/Pop		N_2O/Pop		CH_4/Pop				NO_x/Pop		SO_x/Pop			
VA/Pop	0.372**	0.342*	0.201*	0.271**	-0.197*	-0.252**	13.989***	11.331***	-1.331***	-510.061**	-5.644***	-2.980***	-2191.7***	-2141.5***
(VA/Pop)2	/	/	/	/	/	/	-0,744***	-0.607***	/	54.245**	/	/	231.554***	226.416***
(VA/Pop)3	/	/	/	/	/	/	/	/	/	-1.924**	/	/	-8.160***	-7.985***
Pop density	/	0,223**	/	-0.490***	/	-1.547***	/	-1.142***			/	0.418**	/	0.414*
FEM/REM	REM	REM	REM	REM	FEM	FEM	FEM	FEM°	FEM	REM§	FEM	REM§	REM§	REM§
Non logarithmic specifications	Not significant	Not significant	Not significant	Not significant	Significant	Not significant	Not significant	Not significant	Significant	Not significant	Same shaped pattern and significant coefficient	Pop density not significant	Not significant and with inverted signs with respect to the log-form	
Comment	Neither EKC or N evidence		Neither EKC or N evidence		EKC evidence				Mixed evidence: linear and cubic both significant; inverted-N shape		Inverted-N shape for the cubic			
Turning point (VA/Pop)							9.401	9.334						
VA/Pop range	log 8.95-10.08 (mean 9.53) - non log 7708.86-23940.27 (mean 14183.71)													
F test and Chi squared prob.	0.047	0.011	0.085	0.000	0.099	0.004	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
N	285	285	285	285	285	285	285	285	285	285	285	285	285	285

Notes:

°In this case the asymptotic assumptions of the Hausman test miss.

§We present the estimates relative to the Random effect specification despite the fact the Hausman test indicates that the Fixed effect specification (with no significant coefficients) have to be preferred.

Table 5b. Empirical evidence: testing the EKC hypothesis for APAT emissions (Logarithmic specifications, years 1990, 1995, 2000; N=285, 3 years*95 provinces)

	NH3/Pop	NMVOC/Pop				CO/Pop					PM10/Pop	
VA/Pop	9.677 (p=0,104)	-1.059***	-1.120***	11.483*	-427.383**	-1.403***	11.94**	13.124***	-443.051**	-425.512**	-0.628***	15.851**
(VA/Pop)2	-0,502 (p=0,109)	/	/	-0.618**	45.655**	/	-0.662**	-0.726***	47.315**	45.525**	/	-0.864***
(VA/Pop)3	/	/	/	/	-1.625**	/	/	/	-1.685**	-1.625**	/	/
Pop density	/	/	-1.726***	/	/	/	/	0.115***	/	0.112***	/	/
FEM/REM	REM	FEM	FEM	REM§	REM§	FEM	REM§	REM§	REM§	REM§	FEM	FEM
Non logarithmic specifications	Both va and va2 significant and with the expected signs (inverted-U shape)	Significant	Significant	Va not significant	Not significant	Significant	Not significant	Not significant	Not significant	Not significant	Significant	Not significant
Comment	EKC shape but significant coefficients only without logarithms	Mixed evidence: quadratic and cubic both significant; inverted-U and inverted-N shape				Mixed evidence: quadratic and cubic both significant; inverted-U and inverted-N shape					EKC evidence	
Turning point (VA/Pop)				9.290			9.018	9.039				9.173
VA/Pop range	log 8.95-10.08 (mean 9.53) - non log 7708.86-23940.27 (mean 14183.71)											
F test and Chi squared prob.	0.199	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
N	285	285	285	285	285	285	285	285	285	285	285	285

Note:

§We present the estimates relative to the Random effect specification despite the fact the Hausman test indicates that the Fixed effect specification (with no significant coefficients) have to be preferred.