Economic Dynamics, Emission Trends and the EKC Hypothesis New Evidence Using NAMEA and Provincial Panel Data for Italy

Massimiliano Mazzanti, Anna Montini
and Roberto Zoboli

NOTA DI LAVORO 24.2007

FEBRUARY 2007

CCMP – Climate Change Modelling and Policy

Massimiliano Mazzanti, *Department of Economics Institutions and Territory,*
University of Ferrara, National Research Council CERIS-CNR, Milan
Anna Montini, *Department of Economics, University of Bologna & National Research*
Council, CERIS-CNR Milan
Roberto Zoboli, *National Research Council, CERIS-CNR Milan & Catholic University of Milan*

Economic Dynamics, Emission Trends and the EKC Hypothesis
New Evidence Using NAMEA and Provincial Panel Data for Italy
Summary

This paper provides new empirical evidence on delinking trends concerning emission-related indicators in Italy. We discuss methodological issues regarding the analysis of delinking and examine the related Environmental Kuznets Curves (EKC) literature to explore and assess the most value added research lines after more than a decade of intensive research in the field. The main contribution of the paper is in providing EKC evidence exploiting environmental-economic merged panel datasets at a decentralized level exploiting long time series and rich cross section heterogeneity at both sectoral and provincial level. This crucially augments the unsatisfactory outcomes deriving from cross country analyses, which are less informative for policy purposes since they provide averages for environmental-economic relationships. Two panel datasets: 1990-2000 emissions at province level; and sectoral disaggregated NAMEA emissions sources for 1990-2001 are analyzed. We find mixed evidence supporting the EKC hypothesis. Some of the pollutants in the NAMEA data, such as CO_2, CH_4 and CO, produce inverted-U shaped curves with coherent within range turning points. Other emission trends for the period under consideration show monotonic or even N shaped (SO_X, NO_X, $PM10$) relationship. Other emissions show relatively less robust results, with mixed evidence arising from different specifications. This partially confirms some of the criticisms directed to EKC empirical investigations. However, our analysis shows that probably there is no single EKC dynamic, but rather many EKC dynamics, differing depending on (i) period of observation; (ii) country/area; (iii) emissions/environmental pressures; (iv) sectors. Sectoral disaggregated analysis highlights that an aggregated outcome should hide some heterogeneity across different sectors. Services tend to present an inverted-N shape 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): though a turning point has been experienced, N shapes may lead to increased emissions with respect to very high levels of the income driver. The analysis of provincial data shows that inverted-U shaped curves are present for some of the emissions in the SINAnet- APAT database, such as CH_4, NMVOC, CO and $PM10$, 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). This kind of analysis at macro sector and/or specific sector level appear to be the most promising and robust field of future research for the assessment of EKC dynamics. National studies grounded in geographical heterogeneity, rather than regional/international analysis, and focused on sectoral trends, are more informative for policy making. The implementation of such investigations needs larger datasets than are currently available. We thus point to the need for increasing and continual effort on constructing integrated environmental/economic statistical accounts.

Address for correspondence:

Massimiliano Mazzanti
Department of Economics Institutions and Territory
University of Ferrara
Ferrara
Italy
E-mail: ma.maz@iol.it

1. Introduction

Indicators of 'decoupling' or 'delinking', that is improvements in environmental/resource indicators with respect to economic activity indicators, are increasingly used to evaluate progress in the use of natural and environmental resources. The OECD has been involved in 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 (EEA) state-of-the-environment reports (EEA, 2003). A few European countries have started to include delinking-oriented indicators in official environmental performance analyses (DEFRA/DTI, 2003). Some countries are considering delinking-based targets for major environmental policies, and the US has adopted an 'emission-intensity' target for its climate policy.

Delinking trends for industrial materials and energy in advanced countries have been under scrutiny for decades[1]. In the 1990s, research on delinking extended to air pollution and GHG emissions, and 'stylised facts' were proposed about the relationship between pollution and economic growth which became know as the 'Environmental Kuznets Curve' (EKC), because of their similarity with Kuznets' (1955) suggestions on long-run income distribution paths[2]. The EKC hypothesis, which is a natural extension of delinking analysis, holds that for many pollutants, there is an inverted-U shaped relationships between per capita income and pollution. The hypothesis is based on conceptual intuition rather than a theoretical model, though recent contributions have demonstrated that the Environmental Kuznets hypothesis can be included in formalised economic models[3]. However, empirical evidence of an EKC for emissions is rather ambiguous. For some pollutants, mainly associated with regional/local impact, there seems to be a 'turning point' (TP) at certain levels of income, but it is generally accepted that certain critical externalities, such as CO_2 and waste flows, monotonically rise with income; at best, there may be a 'relative delinking' (Stern, 2004)[4].

The aim of this paper is twofold. First, we present some empirical evidence for Italy related to EKC dynamics concerning emissions from the National Accounts Matrix including Environmental Accounts (NAMEA), using the 1990-2002[5] database which was recently updated by the National Institute of Statistics (ISTAT). The novelty of our study lies in our use of NAMEA accounting, which is a panel of observations for emissions from several

---

[1] For extensive evidence and review and discussion on the period prior to the early 1990s see Tilton (1988, 1991) on metals/materials, Martin (1990) on energy, and Zoboli (1995). For a recent thorough analysis of long run energy trends see Ayres et al. (2004), Gruebler et al. (1999) and many IIASA publications, available at 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] The EKC hypothesis does not originally stems from a theoretical model, but recent contributions have started showing how it may be included in formalised economic models. A seminal recent paper which surveys the literature and presents a model where sources of growth, increasing returns to abatement, income and threshold effects are the main drivers of EKC is by Copeland and Taylor (2004). See Andreoni and Levinson (2001), who set the EKC within a microeconomic production function framework, showing that increasing returns from abatement are a key explanation of EKC shapes, Chimeli and Braden (2005), Bella (2006), who presents an endogenous growth model related to EKC reasoning, De Vita (2003), who dynamically analyses discount rate issues, and Kelly (2003), who find that the EKC shape depends on the dynamic interplay between the 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; we excluded 2002 because in that year a different estimation methodology for emissions was applied.

productive branches of the economy (Femia and Panfili, 2005). We use a disaggregation of emissions for 29 branches[6].

Second, we present complementary evidence based on the emissions considered in the NAMEA data at geographical not sectoral level. Provincial data on emissions for the years 1990, 1995 and 2000) are available from official statistics. We merged our database with the provincial value added (see par.3 for details about the data). We consider that this constitutes an original contribution to the EKC literature, since we provide empirical evidence using national level data, exploiting two different disaggregations (sectoral and geographical) which should provide greater heterogeneity and more robust results.

We would stress that the research on EKC is moving towards analysis at national and regional level analyses which are more informative for policy makers, since they capture the specific dynamic of a country. These may differ from the average dynamics observed in cross country panel data investigations, and may also be more robust in statistical terms since they exploit data sources with stronger heterogeneity.

The paper is structured as follows. Section two presents the EKC framework and outlines the main methodological and empirical issues. Some recent studies are reviewed in order to define the state of the art and where value added may be obtained. Section three presents and discusses our two datasets. Section four presents the empirical model and main findings. Section five concludes.

2. Delinking, environmental efficiency and the EKC framework

2.1 Defining a proper use of delinking and EKC analyses

The relationships between 'delinking' and EKC approaches, and some of their limitations can be discussed within the framework of a simple IPAT model. IPAT defines total impact (I, i.e. atmospheric 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 suited to 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 P and A as drivers of I is clear, the exact meaning of T requires some further explanation. It is an indicator of 'intensity' and measures how many units of Impact (natural resource consumption) are required by an economic system to 'produce one unit (one dollar) of GDP. As a technical coefficient representing the 'resource-use efficiency' of the system (or if reciprocal GDP/I is considered, 'resource productivity' in terms of GDP), it is the most aggregated way of representing the average 'state of the technology' of an economy *in terms of* the Impact variable. Changes in 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 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 examined in the delinking analysis. T is the main 'control variable' in the

---

[6] Accounts were not available for all 50 branches for the first years. Thus we could not use the full breakdown as data losses would have been too large. We structured the panel assigning equal weight to temporal and cross section heterogeneity, rather than biasing towards the latter by using a shorter run but larger dataset.

system. In a cross-country setting, The interpretation of T is less clear cut, but delinking can emerge again as a negative relationship between I and the level of GDP or GDP/P.

Within an IPAT framework, three aspects of 'delinking analysis' and 'EKC analysis' emerge.

First, delinking analysis or observation of T on its own may produce ambiguous results. Decrease in the variable I over time is commonly defined as 'absolute decoupling', even though it is not a delinking process as it says nothing about the role of economic drivers. An environmental Impact that is slower growing (or slowly diminishing) than the economic drivers, i.e. a decrease of T, is generally described as 'relative delinking'. Thus, 'relative delinking' could be strong, while 'absolute delinking' might not occur (i.e. if I is stable or increasing) if the increasing efficiency is not sufficient to compensate for the 'scale effect' of other drivers.

Second, a delinking process, i.e. a decreasing T, suggests that the economy is more efficient, but offers no explanations of what is driving this process. In its basic accounting formulation, the IPAT framework implicitly assumes that the drivers are all independent variables. However, the evidence on the dynamics of economic systems suggests that *each* driver, as well as the Impact, may be reciprocally interdependent through a network of direct/indirect causations. For example, the evidence suggests that population dynamics (P) depend 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, in general, T can depend on GDP or GDP/P, and *vice versa*, if T refers to a key resource such as energy. In addition there is a relationship between changes in the dynamics among P and I and T (Zoboli, 1996). For example, 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 mechanisms (changes in 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 through which I influences T, while models including 'endogenous technological change' capture some influences of both I and GDP on T. In fact, improvements in T for a specific I can also stem from general techno-economic changes, e.g. 'dematerialisation' associated with ICT diffusion, which are not captured by resource-specific 'induced innovation' mechanisms and can vary widely for given levels of GDP/P depending on the different innovativeness of similar countries. Then, a decrease in T can be related to micro and macro non-deterministic processes also involving dynamic feedbacks, for which economics proposes an open set of interpretations.

Third, EKC analysis addresses one/two of the above relationship, i.e. between I and GDP or between T and GDP/P. It examines 'benefits' and 'costs'. Even though it may highlights empirical regularities that are of heuristic value, it does not provide satisfactory economic explanations. 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, and thus de-links from income due to a steady improvement in T. More specifically, it predicts that 'environmental income elasticity' decreases monotonically with income, and that its sign eventually changes from positive to negative thus defining a turning point for an inverted-U shaped relationship. Here, we do not address the different meanings 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, but note that if the relationship is between I and GDP, the EKC provides the same information as the analysis of T.

Furthermore, if I and GDP show an EKC, then there should also be one between T and GDP because, with some exceptions, both P and GDP are generally increasing over the long run, and delinking must have occurred at some level of GDP. However, in the case of an EKC between T and GDP or GDP/P, it is not necessarily the case that 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, was able to compensate for. This is what occurs in the case of global CO_2 emissions over the very long run. When relying on GDP or GDP/P as the only explanatory variable, EKC suffers from the shortcomings highlighted above for delinking analysis, but with an additional risk. The existence of an EKC could be deterministically misleading in suggesting that rapid growth towards high levels of GDP/P *automatically* produces greater environmental efficiency, i.e. 'absolute' or 'relative' delinking, and thus can be the 'best policy strategy' to reduce environmental Impact. However, from the IPAT framework, it is clear that GDP, or GDP/P growth, by itself implies a 'scale effect' on I, i.e. a growth in 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 that, based on no predefined theoretical model but rooted in Kuznets' seminal work, empirically studies whether or not, for pollutants and other environmental indicators, an inverted-U shaped curve can be observed. Although EKC does not rely on a specific economic model, many theoretical assumptions, on both the consumption and production sides, are implicitly tested within the empirical context of EKC. 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 within the wider policy effect). Copeland and Taylor (2004) presents a model where sources of with (trade, capital accumulations sectoral composition), increasing returns to abatement, and income / threshold policy effects are defined as main explanations (drivers) for EKC dynamics. Thus, in knowing the benefits of a EKC multivariate econometric-based analysis, we must be fully aware of the costs, and try to find pragmatic ways to mitigate them. This involves identifying the main deficiencies and weaknesses of EKC.

We need to pay particular attention to deriving policy implications. EKC studies use different environmental indexes (absolute, per capita, output based, input based, per unit of GDP) and there is no consensus about which indicators should be used. However, different measures produce different implications and are open to different interpretations. For example, using per capita measures for the OECD countries would produce few problems, and absolute measures could be avoided, if we measure intensity on the vertical axis the presence of a lower bound implies that total emissions are growing at the same rate as income in a sort of 'steady state' equilibrium. Thus, the vertical and horizontal axes measures must be compatible. There is also no consensus about the type

---

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

and number of explanatory factors that can be introduced as potential drivers of environmental performance. Some studies use only income variables; others include several socio-economic variables with the (correct) aim of extending the conceptual setting behind the EKC empirics (Harbaugh et al., 2002); while a few include policy drivers (Markandya et al., 2006). The choice obviously depends on data availability and research objectives.

The nature, quality and availability of data are crucial issues. The first wave of the EKC literature includes a large majority of contributions focused on the analysis of cross-country datasets, generally taken from official OECD and World Bank sources. However, the quality of macro data for some regions (non OECD countries) has been questioned, and even the use of panel datasets does not allow specific country-level coefficients for the income-environment relationship to be calculated. The key fact here is that there are many different relationships that can apply to different categories of countries. In other words, the policy relevance of world-wide cross country analyses is limited. Future research, as we highlight in the conclusions to this paper, should focus on delinking analysis that exploits datasets which include environmental and economic indicators at provincial/regional level (at European/national level). It follows that the value added from studies based on national/regional datasets will be higher than from those based on international datasets[8]. The more micro-based (regionally/locally disaggregated) the evidence, the better it is for statistical and policy aims.

This paper aims at providing new evidence in this area. We would argue that the research lines providing the most value added are, as the literature we review below highlights: the comparison of parametric and non parametric models which test the relevance of functional forms (and within the parametric world of homogenous and heterogeneous panel specifications); and, not necessarily separate from the former empirical studies of national cases disaggregated at regional level. One emerging result is that, irrespective of their statistical robustness, for most environmental pressures, large cross country datasets do not provide sound outcomes because different EKC shapes may be associated with different units of the sample under analysis. More interesting results, and richer in terms of economic and policy relevant interpretations, may stem from databases of homogenous sets of countries or, perhaps even better, national cases. The EKC may ultimately turn out to be country specific.

2.3 EKC analyses: recent evolutions

We refer to Ekins (1997), Dinda (2004, 2005), Cole et al. (1997), Cole (2003), Stern et 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 of these papers refer to some of the seminal studies in the delinking and EKC literature.

Below, we provide a short critique of some of the most recent contributions in the field, on the basis of the value added that they provide in terms of methodological issues and new empirical evidence on EKC dynamics for

---

[8] Bimonte (2002) makes this point in exploiting a cross sectional dataset of European countries on the 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 terms is higher when focusing on more homogenous cross country or within country datasets.

major emissions/environmental pressures[9]. The focus is primarily on major emissions and especially CO_2, studies of which are of major importance 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 in order to highlight current research within the EKC framework and to collocate our investigation with respect to the recent empirical contributions.

Cole et al. (1997) and Stern (1998) showed that evidence from the first wave of studies, relying on data until the late eighties, was generally that an EKC was present only in the case of local air and water pollutants, but not waste, while indicators with more global or indirect effect were increasing more or less monotonically with income. Empirical evidence in support of an EKC dynamics, or delinking between emission and income growth, is more limited and less robust concerning CO_2 in relation 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 for many important world economies (Vollebergh and Kemfert, 2005), and where delinking is observed, it is mostly relative rather than absolute, as assumed by EKC hypothesis (Fischer - Kowalski and Amann, 2001[10]).

Some recent works, on the basis of updated data and new techniques, have highlighted 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 is clear that, at least as far as OECD countries are concerned, some EKC evidence even for CO_2 is emerging producing a more optimistic picture to counterbalance some of the less optimistic views (Harbaugh et al., 2002; Stern et al., 1996; Stern, 1998, 2004). Nevertheless, it should be noted that a robust assessment of results is under way and there are some critical points and ambiguous heterogeneity across models and different contributions that are still to be resolved.

Our survey is specifically focused on the largest stream of analysis which deals with atmospheric emission related environmental issues, though some reference is made to other issues such as 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. Table 1 presents some contributions and considers the aforementioned issues of methodology, the environmental pressure considered, the nature of the data and the evidence.

Although the studies we reviewed are all based on long time periods, most take the country (mainly an OECD country) as the unit of analysis and in only a few cases is within country disaggregation implemented (at US state level). Parametric and non parametric specifications are used and in several cases there is evidence that an inverted-U shaped curve depends on the econometric method used and is quite sensitive to the degree of heterogeneity included in the panel estimations.

We can summarise the studies reviewed by saying that different types of value added are currently possible by estimating (i) panels with slope and intercept heterogeneity, which, as noted by Baltagi et al. (2002) are

---

[9] A longer version of the survey is found in Mazzanti, Montini and Zoboli (2006b)

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

nevertheless not the panacea; (ii) single country panel datasets where within country heterogeneity is exploited; (iii) specific time series at national or state/regional level, providing data availability for sufficiently long time series. We argue that future empirical efforts should be concentrated using newly constructed, more heterogeneous and longer datasets at country level or for samples of countries in homogenous relevant areas, rather than cross country international datasets which may produce very different stories and hide some vital results (Brock and Taylor, 2004).

The exploitation of geographical and sectoral disaggregated data is, in our opinion, one of the research lien that may provide great advancements in the EKC literature, since it goes deeper into the (in-country) dynamics concerning emissions and economic drivers, as well as technological developments (i.e. stock of capital data are a likely possible factor that can be used in NAMEA-based investigation, given its availability at sector level). Other lines refer to specific environmental realms that historically lack evidence, such as waste (Mazzanti, Montini and Zoboli, 2006a; Johnstone and Labonne, 2004; Kaurosakis, 2006). Finally, it is worth mentioning that a field of great increasing relevancy, which derives from the integration of EKC analyses, international trade analyses and economic dynamics – technological analyses, is the one associated with the so called "pollution displacement" hypothesis. Among the recent works, we refer to Copeland and Taylor (2004) for a general overview on all such integrated issues, and to Cole (2003), Muradian et al., (2002), Grether et al (2006), Managi (2006b), Cole et al (2006) for some empirical evidence, using both aggregated and disaggregated industry datasets. This is an area of important research where (the construction of) data sources represent a strong constraint for carrying out sound analyses.

Our survey was in fact instrumental in drawing out what the main (value added) lines of current research in the EKC literature are. It is worth noting that the recent literature casts doubt on the foundations of EKC results, and stresses their contingency on the empirical model and specifications used (Harbaugh et al., 2002[11]; Stern, 2004, 1998;). Though this is a core issue which needs further research, we believe with other authors that the EKC setting, though improvable both at a theoretical and empirical level, is model frame which may still generate useful insights for the understanding of ecological-economic dynamics and for policy evaluation (Copeland and Taylor, 2004)[12].

National based studies which exploit a rich source of within country heterogeneity and test the robustness of results within the boundaries of panel parametric specifications[13] provide value added and implications for

---

[11] The authors conclude quite sceptically on EKC, showing that results are sensitive to econometric modelling, time span and selected countries. Nevertheless, this may be also evidence in favour of investigations that move from cross country analyses, not robust, sensitive to specifications, less policy relevant, towards in-country analyses that, based on higher sector/geographical heterogeneity, provide more specific (less general) but more robust and more policy relevant outcomes. The necessity of pursuing country analyses is also suggested by Brock and Taylor (2003).

[12] The authors, in their critical surveys of theoretical and applied issues, claim on the one hand that EKC studies have suffered from mixed results and from a weak link between theory and empirics. Nevertheless, they argue that the literature has made two main significant contributions: launched an agenda along the trade-environment links, and provided evidence, all in all, that there exists an income effect which raises environmental quality. Though they focus on international policy and trade issues, they point out, among the other things, some hints that worth noting to us (i) (changes) in the sources of growth are a main element in the theoretical explanation of EKC, as well as income effects, threshold/policy effects, increasing returns to abatement. Among the sources of growth (capital accumulation, trade), the composition of the economy, captured by the NAMEA dataset, plays also a key role.

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

policy, given the length of the time series, the relevancy of the period under scrutiny, the cross section heterogeneity and the analysis of different specifications[14]. Most flaws may be resolved or mitigated by increasing the quantity and quality of data used in country specific analysis (Caratti et al., 2006). Macroeconomic analysis at a relatively disaggregated geographical level may be the good compromise and the best choice between microeconomic based studies, difficult to generalise, and macroeconomic investigations based on cross-country datasets[15]. As suggested in their conclusions by Copeland and Taylor (2004), recent research finding a sensitivity of the EKC to time periods or data may reflect the working of important excluded national characteristics

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, using panel disaggregated data at both sectoral and provincial level. We argue that the exploitation of disaggregated data is another way of improving understanding of the income–environment relationship, providing a natural ground rich in heterogeneity, in addition to recent studies which have attempted to add to and 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).

Second, based on our extended dataset, we analyse the EKC shapes for manufacturing and services separately, in order to check whether the average picture differs from the sub sample analyses. The use of sub sample analysis was suggested by the conceptual perspective, specifically the NAMEA[16] data (Femia and Panfili, 2005) and was shown in recent works to be an effective way, for example, of focusing on different geographical areas (Martinez Zarzoso et al., 2004; 2006; Mazzanti, Musolesi and Zoboli, 2006). As far as our work is concerned, and for work on industrialised countries in general, 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 the first, or at least one of the first studies, to test the EKC hypothesis on a developed country by exploiting a panel matrix of emissions and value added data for 29 main economic

---

[14] Caratti et al (2006) survey the availability of environmental data across different official international sources. Their investigation highlights that main added value could derive from studies that exploit newly available disaggregated data at national/regional level, and on specific realms such as waste.

[15] This is true for all the EKC literature. Concerning air emissions, we quote List and Gallet (1999) who present evidence on the US using state level SO_2 and NO_X emissions from 1929 to 1994. In summary, the large majority of states follow an 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 countries though associated to an EKC shape witness higher than the average turning points. Thus, traditional panel analysis may lead to overly optimistic conclusions, driven by the result which represents the average picture, hiding specific EKC dynamics by states or regions within countries. See also the recent varied evidence provided by Managi (2006a,b) on US and Japanese data, who supports the idea that analyses based at a more disaggregated geographical or sectoral level are needed for advancing the EKC literature.

[16] See the works by Ike (1999), Vaze (1999), Haan and Keuning (2000) and Keuning et al. (1999), among others, who provide descriptive and methodological insights on NAMEA for some major countries. Steenge (1999) provides an analysis of NAMEA with reference to environmental policy issues, while Nakamura (1999) exploits Dutch NAMEA data for a study on waste and recycling along and input-output reasoning. We claim that NAMEA exploitation by quantitative methods may provide, currently and in the future, a great contribution to advancements in EKC and policy effectiveness analyses.

production branches, from agricultural to manufacturing and services. This is an alternative approach to the analysis of national EKC specificity, with respect, for example, to time series studies which investigate structural changes in the economy over the long run (Lindmark, 2002).

3.1 The dataset: sources and value added

The main source of data on sectors-pollutants is the National Accounts Matrix including Environmental Accounts (NAMEA) recently published by ISTAT. The first NAMEA, referring to 1990 data, was published in ISTAT (2001); in the following years several other NAMEA were published up to 2002. Nine air pollutants[17] are considered by NAMEA data and they refer to emissions from several economic activities that we have recoded using 29 productive branches (2 in the agricultural sector, 18 in the industrial sector, 9 in the service sector including public administration) for 1990-2001 (see Tables 2a and 2b for the specification of branches and some descriptive statistics). Other data on national value added and units of labour (full time equivalent jobs) are also included in the NAMEA[18].

The air emissions data collected in the provincial dataset are drawn from the SINAnet-APAT database[19] which contains information for 21 pollutants and three years 1990, 1995 and 2000[20]. From those 21 pollutants, we chose the nine that are considered in the national level dataset (sectors-pollutants).

Our processing of ISTAT data was made to obtain the 1990 per capita value added at 1995 prices comparable with respect to the ISTAT 1995 and 2000 value added data. ISTAT was also the source of the population and territory surface data.

The dataset contains information relating to the 95 Italian provinces that existed prior to 1995, before the introduction of eight new provinces . The 1995 and 2000 ISTAT value added data contain data for the eight new provinces, while the APAT emission data contain data for the new provinces only from the year 2000. For this reason we chose to include the Italian provincial subdivisions that existed pre-1995[21].

For the seven provinces from which the eight new ones were derived in 1995, the 1995 and 2000 value added data were calculated with a weighted average for the resident population in the sub-provinces. The population for the same seven provinces were obtained from the sum of the population resident in the sub-provinces. Finally, the 2000 emission data for the eight new provinces were added to the figures for emissions for the old provinces in order to have full comparability with the 1990 and 1995 data.

---

[17] 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 were excluded from the analysis.
[18] 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 the economic and environmental sides.
[19] The air emissions derive from more than 300 human and biogenic activities and are estimated according to CORINAIR methodology.
[20] Unfortunately, the provincial emissions are estimated only every 5 years.
[21] In the other case – by considering the 103 provinces - we could not use the 1990 and 1995 SINAnet-APAT data or would have had to restrict our analysis to the 88 provinces not affected by the administrative changes.

3.2 Methodological issues and the empirical model

The first methodological problem was related to specifying the EKC functional relationship on which there is no consensus. Some authors adopt second order polynomial, others estimate third and even fourth order polynomials, comparing different specifications for relative robustness. It is worth noting that neither the quadratic nor cubic function can be considered a fully 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 polynomials could also lead to N rather than U shaped curves, introducing new problems in understanding the income-environment phenomenon for policymaking. The N shape is justified by a non-linear effect on the scale of economic activity on the environment, which is difficult to prove[22]. Finally, the use of the income factor only, without quadratic and cubic terms, would collapse the EKC analysis to the basic decoupling analysis.

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

(1) $\log(\text{Emission/employees}[23]) = \beta_{0i} + \alpha_t + \beta_1 \text{Log(Value added/employees)}_{it} + \beta_2 \text{Log(Value added/employees)}^2_{it} + \beta_3 \text{Log(Value added/employees)}^3_{it} + e_{it}$

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

Thus, for each combination of the dependent 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 effects and random effects models is compared by the Hausman statistic. We also test the presence of first order serial correlation[24], AR (1) to verify whether this significantly affects the estimates.

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

---

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

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

[24] 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 takes the fitted residual in time T and the vector of explanatory factors as the dependent variable. 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. 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 the presence of correlation in models that involve relatively slowly changing variables, such as 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 has 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.

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 the base case, but also as a term of comparison and of external validity we use the estimation of a non logarithmic model. In most cases, the fixed effects specification[25] is preferred by the Hausman test, though we do not highlight any significant difference between the two models in the few cases the test favours 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 time period effects are included and in AR1 specification. Turning points (TPs) for CO_2, CH_4, NH_3 and CO are 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 with 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 these two emissions are the ones indicated by the literature as most likely to present EKC dynamics across different countries. It seems 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 positive elasticity with respect to high levels of income. This also confirms recent evidence on these two leading indicators. Similar evidence was obtained for PM10 and NMVOC.

Non logarithmic regressions confirm the EKC dynamic for CO_2 and CH_4. In this framework, N_2O and NMVOC also 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 turned over a new path of growing emissions with respect to income.

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 changes the shape to a EKC quadratic specification.

Finally, NH_3 is associated here with an N shape rather than EKC evidence, while PM10 and CO do not lead to significant regression as far as 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 dependent on the chosen specification. Nevertheless, we underline that logarithmic specifications are preferred for these kinds of data, since they smooth the environmental and economic trends. However, although non logarithmic models change some results, they do not sharply affect our structural conclusions based on the logarithmic specifications. Logarithmic specifications

---

[25] We estimate the EKC model by NLogit 3.0, using a least square dummy variable specification (LSDV), fixed effects (FE). The Hausman test generally provides evidence in favour of the FE model, nevertheless, results do not differ sharply when the random effects model is estimated. We use a LSDV model since we are not interested specifically in estimating individual fixed effects, which may be inconsistently estimated when sample size increases. On the other hand, the alternative within-effects 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).

show that most emissions are associated with EKC trends (four to 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)[26].

Finally, it should be noted that we tested the influence of sector dynamics by including dummies for services, manufacturing and other industries; these variables were 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

Our empirical analysis here is focused on the individual branches. The advantage is that it allows us to observe potential differentiated dynamics of the productivities link between services and manufacturing. The disadvantage is the lower statistical robustness due to data losses from splitting the full dataset. Thus, we estimate only base specifications (without AR1 corrections).

Table 4 presents a summary of the empirical evidence differentiating between services (E-O), Industry (C-F) and manufacturing only (D)[27]. We provide comments on the main results. More detailed outcomes are available upon request.

The analysis for the disentangled economic branches highlights that the EKC pattern is influenced by different sectoral dynamics. It adds information to our descriptive findings. For example, commenting on the 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 might expect. The reason may be that those sectors induce matter transformation even if the 'product' is not directly material.

The evidence is heterogeneous across emissions. In previous aggregate analysis, five out of nine emissions emerged as being associated with an EKC dynamics, while three showed signs of N shapes. Let us analyse what are the driving forces of those trends at sectoral level. Within the former group of emissions, the CO_2 trend appears to be driven by industry/manufacturing, but not services. The picture for CO is similar. Disaggregated evidence for CH_4 confirms that the aggregate picture for EKC is driven by all three macro sectors.

N_2O can be considered to be an outlier. The EKC turning point was outside the range observed above. The sectoral analysis shows weak evidence for N shapes in industry and manufacturing; agriculture is not considered due to lack of data. This may represent a flaw since agriculture is the main driving sector. The evidence for NH_3 is the same although it highlights the leading role of manufacturing in explaining aggregated EKC evidence.

Within the emissions displaying N shapes at aggregate level, we note that for trans boundary ones such as NO_X and SO_X, services are associated with a negative trend, though the effect of industrial sectors is likely to overwhelm it. SO_X in particular shows U shapes, which are also observed at aggregate level. In contrast, the PM10 N shape is driven by all sectors, with services associated to a positive relationship, and industry showing

---

[26] Table 2 also presents estimates based on value of production rather than value added. The correlation between value added and value of production is 0,72. The evidence that emerges is for an inverted-N shape in six cases and an N shape in three. Cubic specifications appear to perform better. Value added in our opinion is the most appropriate independent income variable in this EKC analysis.

[27] See Femia and Panfili (2005) for a descriptive analysis of eco efficiency (emission on value added) on different sectors, 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.

some signs of an inverted-U. Finally, NMVOC mixed evidence is explained by an N shape for manufacturing balanced by inverted-N shapes linked to services and industry.

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

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

Evidence from a disaggregated dataset in geographical units is important since it complements the previous analyses which provide evidence (in favour or not) of a delinking based on emissions and income trends associated with value added from industrial and services activities, but omitting, for example, the role of the 'household' sector (in energy consumption) and the effect of private transport on emissions. The observed trends could thus differ. In this case, critical reasoning is needed about 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.

Based on the provincial data, the analysis provides mixed evidence in support of the EKC hypothesis (Tables 5a and 5b)[28]. Some of the pollutants in the SINAnet-APAT provincial database, such as CH_4, NMVOC, CO and PM10, show inverted-U shaped curves for the three periods 1990, 1995 and 2000 considered, with coherent within-range turning points despite quite low (from 8,200 to 12,100€).In the case of NMVOC and CO, however, the cubic specification shows an inverted-N shape. 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)[29]. NH_3 emissions show evidence of a partial EKC, with an inverted-U shape significant in the non logarithmic specifications only.

5. Conclusions

This paper has provided 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 the decentralized level, based on long times series and rich cross section heterogeneity at both sectoral and provincial level.

---

[28] Within the field of country based analyses exploiting geographical data, we highlight Lantz and Feng (2006) who analyse a five region, 30 years panel dataset for Canada, and find 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 sector considered, and also the geographic/economic disaggregation of reference (geographical unit). That is to say, the EKC hypothesis refers to multi faceted empirical evidence, where many EKCs eventually occur. 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 resulting from our analysis, highlight the non-deterministic nature of the processes behind EKC.

[29] Comparing the outcomes in par 4.1 and 4.2, we can deduce that EKC trends for CO_2 are driven by production activities, while household economic activities tend to show a monotonic relationship (which explains the evidence when accounting for all national emissions). The reverse is true for SO_X and NO_X.

The evidence from this type of investigation, in our opinion, is more informative than that from cross country studies which predominate in the EKC literature. The ongoing research directions surveyed in section 2 are valuable. Here we focus on the necessity of exploiting EKC trends using within country disaggregated data. This directly informs European debate over the implementation of environmental policies. Most policies currently are implemented by establishing homogeneous targets across countries, leaving some space for different application of policy instruments. The setting of similar targets is coherent with the hypothesis that the trend characterizing countries in terms of environment-growth relationships is more or less the same for all countries. However, if as some of the in depth analyses of heterogeneity in cross country panel investigations are demonstrating, it is shown that trends differ concerning the elasticity and/or the eventual turning points across countries, the argument in favour of (full or partial) differentiation in terms of national targets will be strengthened.

We found mixed support for the EKC hypothesis. Inverted-U shaped curves for the period considered here were present for some of the pollutants in the NAMEA matrix, for example, 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). The results for other emissions were relatively less robust, with mixed evidence from different specifications. This partially reinforces some of the recent criticisms of EKC empirical investigations. However, the major finding from our analysis is probably that there is no one EKC dynamic, but that many EKC dynamics exist depending on (i) period of observation; (ii) country/area; (iii) emissions/environmental pressures; (iv) sectors. The inspiration for further analytical work should be that not only are EKC dynamics specific to a country or a region, but they are also specific within countries , to sectors and sub geographical areas. The degree of (technological) development is highly differentiated by sector and geographical entity. In fact, a sectoral disaggregated analysis highlights that aggregate outcomes will hide some of the 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 highlights criticalities. The same is true for industry where although there is evidence of a turning point, N shapes may lead to future increases in emissions with respect to the income driver.

The evidence arising from the provincial dataset is mixed in terms 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 inverted-N shapes (SO_X and NO_X). NH_3 emissions show some evidence of EKC, with an inverted-U shape significant in the non logarithmic specifications only. The two analyses are not directly comparable despite being over the same time period. The differences in the results obtained could be attributable 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 related to the sectoral data. Thus, the stronger and more robust evidence of an inverted-U shape for most pollutants may in part be due to the bigger role of main productive activities with respect to the household sector and private transport, and in part due to the structure (length and width) of the two panel datasets. Further investigations will be needed.

We would suggest that future applied research should focus on other national contexts and be grounded in geographical heterogeneity rather than cross country analysis, and should focus on sectoral trends, which are

more informative for economics and policy making. Cross country studies at regional level (e.g. $EU_{15/25}$, US, etc.) may be useful for studying the relative effectiveness of heterogeneous policy efforts across countries which are homogenous in relation to other structural features. Robust implementation of investigations disaggregated by sectors and geographical units requires large datasets. We thus highlight the need to expend increasing and continual efforts on the construction of integrated environmental/economic statistical accounts at national level, by intensifying disaggregated data collection efforts at sectoral and geographical level. The value of both cross section and time series heterogeneity needs to be recognised.

References

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

Auci, S. Becchetti, L., 2006, The instability of the adjusted and unadjusted environmental Kuznets curves. *Ecological Economics*, vol.60, n.1, pp.282-98.

Ayres R.U. Ayres L.W. Pokrovsky V., 2004, On the Efficiency of US Electricity Usage since 1900, Interim Report IR-04-027, IIASA, Luxemburg.

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

Baltagi B. Bresson G. Pirotte A., 2002. Comparison of Forecast Performance for Homogenous, Heterogeneous and Shrinkage Estimators. Some Empirical Evidence from US Electricity and Natural Gas Consumption, *Economic Letters*, vol.76, pp.375-382.

Bella G., 2006, Transitional dynamics towards sustainability: reconsidering the EKC hypothesis, Nota di lavoro FEEM, n.129, FEEM, Milan.

Bimonte S., 2002, Information access, income distribution and the EKC, *Ecological economics*, vol.41, pp.145-56.

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

- 2003, The kindergarten rule of sustainable growth, NBER working paper n.9597, NBER, Cambridge, MA.

Bruvoll A., Medin, H., 2003, Factors behind the environmental Kuznets curve. A decomposition of the changes in air pollution, *Environmental and Resource Economics*, vol.24, pp.27-48

Caratti P. Ferraguto L. Riboldi C., 2006, Sustainable development data. Availability on the internet, Nota di lavoro FEEM, n.125, FEEM, Milan.

Carson R. McCubbin R., 1997, The relationship between air pollution emissions and income: US data, *Environment and Development Economics*, vol.2, n.4, pp.433-450.

Chimeli A., Braden J., 2005, Total factor productivity and the Environmental Kuznets curve. *Journal of Environmental Economics and Management vol.*49, pp.366-80.

Cole M. Rayner A. Bates J., 1997, The EKC: an empirical analysis. Environment and Development Economics 2: 401-16.

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

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

Cole M. Elliott R. Shimamoto K., 2006, Why the grass is not always greener: the competing effects of environmental regulations and factor intensities on US specialization, *Ecological Economics*, vol.54, pp.95-109.

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

De Bruyn S. Van den Bergh J. Opschoor J., 1998, Economic growth and emissions: reconsidering the empirical basis of EKC. *Ecological Economics* vol.25, pp.161-75.

DEFRA/DTI, 2003, Sustainable Consumption and Production Indicators. London, DEFRA.

Dinda S., 2005, A theoretical basis for the EKC, *Ecological Economics*, vol.53, n.3, pp.403-13.

-2004. Environmental Kuznets curve hypothesis: a survey. *Ecological Economics* vol.49, pp.431-55.

Di Vita G., 2003, Is the discount rate relevant in explaining the EKC?, nota di lavoro FEEM, n.83, FEEM, Milan.

EEA, 2003, Europe's environment: The third assessment. Copenhagen, European Environment Agency.

Ekins P., 1997, The Kuznets curve for the environment and economic growth: examining the evidence, *Environmental planning*, vol.29, pp.805-830.

Femia A. Panfili P., 2005, Analytical applications of the NAMEA, Paper presented at the annual meeting of the Italian Statistics society, Rome.

Fischer Kowalski M. Amann C., 2001, Beyond IPAT and Kuznets Curves: globalization as a vital factor in analyzing the environmental impact of socio economic metabolism. *Population and the environment* vol.23.

Fonkych K. Lempert R., 2005, Assessment of environmental Kuznets curves and socioeconomic drivers in IPCC's SRES scenarios, *Journal of environment and development,*vol.14, n.1, pp.27-47

Galeotti M. Lanza A. Pauli F., 2006, Reassessing the EKC for CO_2 emissions: a robustness exercise, *Ecological economics*, vol.57, n.1, pp.152-63.

Galeotti M. Manera M. Lanza A., 2006, On the robustness of robustness checks of the EKC, Nota di lavoro FEEM, n.22, FEEM, Milan.

Greene W.H., 1997, *Econometric Analysis*, 3rd edition, London: Prentice Hall.

Grether J.M. Mathys N. de Melo J., 2006, Unravelling the world wide pollution haven effect, Nota di lavoro 122, FEEM, Milan.

Grossman G.M. Krueger A.B., 1994, Economic growth and the environment, NBER Working Papers 4634. NBER.

Gruebler A. Nakicenovich N. Victor D.G., 1999, Dynamics of energy technologies and global change *Energy Policy* vol.27, pp.247-280

Halkos G., 2003, EKC for sulphur: evidence using GMM estimation and random coefficient panel data models, *Environment and development economics*, vol.8, pp.581-601.

Harbaugh W. Levinson A. Wilson D., 2002, Re-examining the empirical evidence for an environmental Kuznets curve. *The Review of Economics and Statistics*, August 2002, vol.84, n.3, pp.541-551.

Holtz-Eakin D. Selden T.M., 1992, Stoking the fires? CO_2 emissions and economic growth, NBER Working Papers 4248. NBER.

Ike T., 1999, A Japanese NAMEA, *Structural change and economic dynamics*, vol.10, pp.122-149.

ISTAT, 2001, *Statistiche ambientali 2000*, Rome.

Johnstone N. Labonne J., 2004, Generation of Household solid waste in OECD countries. An empirical analysis using macroeconomic data, *Land Economics*, vol.80, n.4, pp.529-38.

Kaurosakis K., 2006, MSW generation, disposal and recycling: a note on OECD intercountry differences, paper presented at envecon 2006: Applied Environmental Economics Conference, 24th March 2006, the Royal Society, London

Kelly D., 2003, On EKC arising from stock externalities. *Journal of Economic Dynamics and Control* vol.27, n.8, pp.1367-90.

Keuning S. van Dalen J. de Haan M., 1999, The Netherlands' NAMEA; presentation, usage and future extensions, *Structural change and economic dynamics*, vol.10, pp.15-37.

Kuznets S., 1955, Economic growth and income inequality. *American Economic Review, Papers and Proceedings* vol.45, n.1, pp.1-28.

Lantz V. Feng Q., 2006, Assessing income, population and technology impacts on CO_2 emissions in Canada: where's the EKC?, *Ecological economics*, vol.57, n.2, pp.182-89.

Lindmark M., 2002, An EKC pattern in historical perspective: carbon dioxide emissions, technology, fuel prices and growth in Sweden 1870-1997, *Ecological economics*, vol.42, n.1-1, pp.333-347.

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

Liu X., 2005. Explaining the relationship between CO_2 emissions and national income: the role of energy consumption, *Economic letters*, vol.87, n.3, pp.325-28.

Managi S., 2006a, Are there increasing returns to pollution abatement? Empirical analytics of the environmental Kuznets Curve in pesticides, *Ecological Economics*, vol.58, n.3, pp.617-36.

- (2006b), Pollution, natural resource and economic growth: an econometric analysis, *International Journal of Global Environmental Issues*, vol.6, n.1, pp.73-88.

Markandya A. Pedroso S. Golub A., 2006, Empirical analysis of national income ad SO_2 emissions in selected European countries, *Environmental and resource economics*, vol.35, pp.221-37.

Martin J.M., 1990, Energy and Technological Change. Lessons from the Last Fifteen Years. STI Review No. 7, July. Paris, OECD.

Martinez-Zarzoso I. Bengochea-Morancho A., 2004, Pooled mean group estimation of an environmental Kuznets curve for CO_2, *Economics Letters* vol.82, pp.121-126.

Martinez-Zarzoso I. Bengochea-Morancho A. Morales Lage R., 2006. The impact of population on CO_2 emissions: evidence from European countries, nota di lavoro n.98, Fondazione Eni Enrico Mattei. FEEM: Milan.

Mazzanti M. Montini A. Zoboli R., 2007, Struttura produttiva territoriale ed indicatori di efficienza ambientale attraverso la NAMEA regionale: Il caso del Lazio. ISTAT, Rome, Forthcoming.

- 2006a, Municipal waste production, economic drivers and new waste policies, Nota di lavoro FEEM, November, Milan, www.feem.it

2006b, Economic dynamics, Emission trends and the EKC hypothesis. New evidence using NAMEA and provincial panel data for Italy, Quaderno di Dipartimento, Università di Ferrara, Dipartimento Economia Istituzioni Territorio, n.19.

Mazzanti M. Musolesi A. Zoboli R., 2006, A Bayesian approach to the estimation of environmental Kuznets curves for CO_2 emissions, ta di lavoro FEEM, October, Milan, www.feem.it

Millimet D., List J., Stengos T., 2003, The EKC: real progress or mis-specified models? *The Review of Economics and Statistics* vol.85, n.4, pp.1038-47.

Muradian R. O'Connor M. Martinez-Alier J., 2002, Embodied pollution in trade: estimating the environmental load displacement of industrialised countries, *Ecological Economics*, vol.41, pp.51-67.

Nakamura S., 1999, An inter-industry approach to analyzing economic and environmental effects of the recycling of waste, *Ecological economics*, vol.28, pp.133-145

OECD, 2002, *Indicators to measure decoupling of environmental pressure from economic growth*. Paris, OECD.

Roy N. van Kooten C., 2004. Another look at the income elasticity of non point source pollutants: a semi parametric approach, *Economic letters*, vol.85, n.1, pp.17-22.

Schmalensee R. Stoker T.M. Judson R.A., 1998, World Carbon Dioxide Emissions: 1950-2050. *Review of Economics and Statistics*, vol.80, pp.15-27.

Selden D.H. Song D., 1994, Environmental quality and development: Is there a Kuznets curve for air pollution emissions?, *Journal of Environmental Economics and Management*, vol.27, n.2.

Shobee S., 2004, The environmental Kuznets curve (EKC): a logistic curve? *Applied Economics Letters* vol.11, pp.449-52.

Steenge A., 1999, Input-output theory and institutional aspects of environmental policy, *Structural change and economic dynamics*, vol.10, pp.161-76.

Stern D., 2004, The rise and fall of the Environmental Kuznets curve, *World Development,* vol.32, n.8, pp.1419-38.

- 1998, Progress on the environmental Kuznets curve? *Environment and Development Economics* vol.3, pp.173–196.

Stern D.I. Common M.S. Barbier E.B., 1996, Economic growth and environmental degradation: the environmental Kuznets curve and sustainable development. *World Development,* vol.24, pp.1151–1160.

Taskin F. Zaim O., 2000, Searching for a Kuznets curve in environmental efficiency using Kernel estimation, *Economic letters*, vol.68, n.2, pp.217-223.

Ten Kate A., 1993, Industrial development and environment in Mexico. Working Paper Series, n. 1125. Washington D.C.: World Bank.

Tilton J.E., 1991, Material Substitution: The Role of New Technology. in: Nakicenovic N. Grubler A. (eds.), *Diffusion of Technology and Social Behavior.* Berlin, Springer-Verlag.

- 1988, The new view on minerals and economic growth, Working Paper 88-10, Colorado School of Mines.

Vaze P., 1999, A NAMEA for the UK, *Structural change and economic dynamics*, vol.10, pp.99-121.

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

Vollebergh, H., Dijkgraaf, E., Melenberg, B., 2005. Environmental Kuznets curves for CO_2: heterogeneity versus homogeneity. Discussion Paper 25, Tilburg University, Center for Economic Research.

Vollebergh H. Kemfert C., 2005, The role of technological change for a sustainable development. *Ecological Economics* vol.54, pp.133-147

Wooldridge J., 2002, *Econometrics Analysis of Cross Section and Panel Dat*a, Cambridge, Massachusetts, The MIT press.

Yandle B., Vijayaraghavan M., Bhattarai M. 2002. The environmental Kuznets curve. A primer, PERC Research Study 02-01.

Zoboli R., 1996, Technology and Changing Population Structure: Environmental Implications for the Advanced Countries. Dynamis-Quaderni, 6/96. Milan: IDSE-CNR. www.idse.mi.cnr.it.

- 1995, Technological Innovation and Environmental Efficiency: Empirical Evidence and Explaining Factors, Dynamis-Quaderni. 5/95. Milan: IDSE-CNR. www.idse.mi.cnr.it.

Table 1 – Recent EKC literature survey

Author(s), (publication year)	Methodological issues (model/estimation technique)	Countries/ geographical focus	Time period	Emissions	EKC Evidence	Turning point	Note/considerations
Auci and Becchetti, (2005)	Parametric specification	197 countries WDI dataset	1960-2001	CO_2	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	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	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	Inverted-U shape	14.000\$-15.000\$; 20.600\$ with slope homogeneity	
Fisher, Kowalski and Amann, (2001)		Richest OECD countries		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	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		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	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	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	Inverted-U shape	NO_X 8000-17000\$; SO_2 15000-20000\$ (\$1987)	
Liu (2005)	Simultaneous model	24 OECD countries	1975-1990	CO_2			
Martinez, Zarzoso and Morancho, (2004)	Panel data; slope heterogeneity	22 OECD countries	1975-1998	CO_2	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			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	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	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	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 effects specifications are presented accordingly to the Hausman test result. The FE model estimated is a LSDV model; individual fixed effects 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$_2$O/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 lack of data.

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 nor N evidence		Neither EKC nor 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 are absent.

§ We present the estimates relative to the Random effects specification despite the fact that the Hausman test indicates that the Fixed effects specification (with no significant coefficients) has 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)

	NH$_3$/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 effects specification despite the fact the Hausman test indicates that the Fixed effects specification (with no significant coefficients) has to be preferred.