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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 CO₂, CH₄ 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 (SOX, NOX, 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 CH₄, NMVOC, CO and PM10, with coherent within range turning points. Other emission trends show a monotonic relationship (CO₂ and N₂O), or in some cases an inverted-N shaped relationship (SOX and NOX). 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.

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

JEL Classification: C23, Q38, Q56

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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 decades¹. In the 1990s, research on delinking extended to air pollution and greenhouse gases (GHGs) emissions, and ‘stylised facts’ were proposed about the relationship between pollution and economic growth which became known as the ‘Environmental Kuznets Curve’ (EKC), because of their similarity with Kuznets’ (1955) suggestions on long-run income distribution paths². The EKC hypothesis, which is a natural extension of delinking analysis, holds that for many pollutants, there is an inverted-U shaped relationship 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 models³. 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 CO₂ 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 1990-2002⁵ 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 stem 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 branches⁶.

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 $I = P \cdot A \cdot T$. 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 CO₂ 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 relationship⁷. 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 datasets⁸. 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.

2.3 EKC analyses: recent evolutions and future prospects

We refer to Ekins (1997), Dinda (2004, 2005), Cole et al. (1997), Cole (2003), Stern et al. (1996), Stern (2004), Managi (2006), Fonkyeh 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 major emissions/environmental pressures⁹. The focus is primarily on major emissions and especially CO₂, studies of which are of major importance given the policy and environmental relevance of the problem and the higher

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.

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

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 CO₂ in relation to local emissions and water pollutants (Cole et al., 1997; Bruvoll and Medin, 2003). Decoupling of income growth and emissions of CO₂ 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, 2001¹⁰).

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 CO₂ 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 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

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.

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 line 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., 2002¹¹; 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 specifications¹³ provide value added and implications for policy, given the length of the time series, the relevancy of the period under scrutiny, the cross section

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).

heterogeneity and the analysis of different specifications¹⁴. 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 datasets¹⁵. 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.

Linking the reasoning strictly to our framework, it is highly relevant to take into account national dynamics when reasoning around the underlying dynamics of emissions and the related policy implementation and policy effectiveness. Some stylized facts may help. Concerning GHGs, mainly CO₂, and other air emissions both the empirical literature discussed above and the general evidence (EEA, 2004) show that signs of at least a relative but also absolute decoupling are emerging at EU level. EEA recently reported that total CO₂ emissions from the 15 EU Member States were 0.5% lower in 2000 than 10 years earlier. However, EU emissions of CO₂ and other greenhouse gases rose between 1999 and 2000. The latest inventory shows that in 2000 total EU greenhouse gas emissions stood 3.5% below their 1990 level. In 1999 they had been 3.8% lower, according to the most recent estimates¹⁶. Acidifying pollutants, ozone precursors, fine particulates and particulate precursors all decreases; despite this partially positive evidence, reductions are largely heterogeneous by country and sectors/economic activities (EEA, 2004). We thus argue that specific in depth country evidence is helpful to inform both national policies and for example the core Clean Air For Europe (CAFE) programme. Though significant reduction of air emissions have been achieved despite growth in population energy use and output, partly explained by EU and national legislation on stationary sources (EEA, 2004), both the evaluation of policy effectiveness and the consequential feeding into new policy schemes should be based on a consistent analysis at country level. The rich and comprehensive reports by the EEA, for example, could be complemented by in depth analysis at national level that rely on data provided by local environmental agency and national statistical offices.

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

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 SO₂ 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 One of the main reasons for the overall emissions rise from 1999 to 2000 was a 2.4% increase in CO₂ emissions from electricity and heat production, due in part to an expansion of power generation from fossil fuels, especially coal, in the UK, the EU's second-largest emitter. Another reason was continued growth in greenhouse gas emissions in Greece, Spain, Ireland, Italy and Belgium (www.eea.europa.eu). This trend confirms that non linearity and N shapes may be associated to the dynamic of environment-development relationship.

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 NAMEA¹⁷ 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 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 ISTAT¹⁸ (2001); in the following years several other NAMEA were published up to the year 2002. Nine air pollutants¹⁹ are considered by NAMEA data and they refer to emissions from several economic activities²⁰ 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 1990–2001²¹ (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

¹⁷ 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.

¹⁸ Italian National statistical agency.

¹⁹ The pollutants considered in NAMEA are only air pollutants: Carbon dioxide (CO₂), Nitrous oxide (N₂O), Methane (CH₄), Nitrogen oxides (NO_x), Sulphur oxides (SO_x), Ammonia nitrogen (NH₃), Non methane volatile organic compounds (NMVOC), Carbon monoxide (CO) and Particulates matter (PM₁₀). Lead (Pb) emissions were excluded from the analysis.

²⁰ NAMEA data also include emissions derived from three household consumption activities (transport, heating and other, such as painting and solvent use) but we have excluded these source of emissions because our interest deals mainly with the productive activities disaggregation (for which the macro sectors are primary, industry and services) and the geographical (provincial) disaggregation available in the SINAnet–APAT data.

²¹ 2002 was excluded due to heterogeneity of data quantification for emissions between 1990–2001 and 2002. ISTAT will provide future homogenous datasets for NAMEA.

equivalent jobs) are also included in the NAMEA²². We also merge NAMEA data with other ISTAT data on sector net capital stocks (1995 constant prices) and import and export flows in order to further investigate the relationship. The merge only reduces the panel to a 1991-2001 series, for the unavailability of year 1990. This merge allows some marginal estimations that are commented on below.

The air emissions data collected in the geographically disaggregated dataset are drawn from the SINAnet-APAT database²³ which contains information, at provincial level, for 21 pollutants and three years 1990, 1995 and 2000²⁴. From those 21 pollutants, we chose the nine that are considered in the national level dataset (sectors-pollutants). The dataset finally contains information relating to the 95 Italian provinces that existed prior to 1995, before the introduction of eight new provinces due to some administrative changes²⁵. 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. In fact, 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 data 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. ISTAT was also the source of the population and territory surface data.

3.2 Methodological issues, the empirical model and research hypotheses

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 prove²⁶. Finally, the use of the income factor only, without quadratic and cubic terms, would collapse the EKC analysis to the basic decoupling analysis.

²² 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.

²³ The SINAnet air emissions derive from more than 300 human and biogenic activities and are estimated according to CORINAIR methodology. Thus, the considered sources of emissions in the SINAnet database are different with respect to those included in the NAMEA data *used* because SINAnet provincial data refer to all the sources of air emissions, consumption included, and not only to the emissions derived from productive activities

²⁴ Unfortunately, the provincial emissions are estimated only every 5 years.

²⁵ 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. 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.

²⁶ Shobee (2004) suggests a third order polynomial specification as a more realistic relationship between environmental degradation and income per capita.

Here we test the hypothesis by specifying a proper reduced form usual in the EKC field (Stern, 2004; Cole, 2003):

$$(1) \quad \log(\text{Emission}/\text{employees}^{27}) = \beta_{0i} + \alpha_t + \beta_1 \log(\text{Value added}/\text{employees})_{it} + \beta_2 \log(\text{Value added}/\text{employees})_{it}^2 + \beta_3 \log(\text{Value added}/\text{employees})_{it}^3 + \beta_4 (\text{Trade openness})_{it} + e_{it}$$

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: the linear regressors only (delinking baseline case), linear and squared terms (EKC most usual case), and finally a cubic specification to ascertain, in case of EKC evidence, whether the trend is reversing again to a path of environment-income positive elasticity.

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 correlation²⁸, 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.

In addition to the analyses carried on the basis of model (1), we investigate further specifications. First, we specify a model that includes as covariates the ratio of capital stocks on employees and its squared term. We limit the focus to squared specification, to test whether the structural pattern observed using value added is confirmed by the accumulation for total capital stocks by sectors.

$$(2) \quad \log(\text{Emission}/\text{employees}^{29}) = \beta_{0i} + \alpha_t + \beta_1 \log(\text{capital stock}/\text{employees})_{it} + \beta_2 \log(\text{capital stock}/\text{employees})_{it}^2 + e_{it}$$

A third specification adds to the two above models the variable *trade openness*, calculated as the ratio between import plus exports and value added, both at current prices.

$$(3) \quad (1) \text{ and } (2) + \beta_4 (\text{Trade openness})_{it} + e_{it}$$

It is worth spending some specific words, linking to the survey of the empirical literature, on those additional analyses provided by (2) and (3).

²⁷ Employees are substituted by the population of the province in the provincial based analysis.

²⁸ 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.

²⁹ Employees are substituted by the population of the province in the provincial based analysis.

The analysis that exploits the stock of capital is conceptually close to other works that have tested capital related variables in EKC specifications. Among the others, we refer to Cole (2003), who adds the K/L ratio to the picture, testing whether capital accumulation have a diminishing effect at the margin. Marginal decreasing effects here link to the EKC hypothesis insofar capital accumulation may be supposed to be a driver of the U inverted environment-income relationship. In our framework the reasoning is somewhat different from usual cross country studies as the one mentioned, where the inclusion of K/L ratios theoretically derives from international trade models of competitive advantage. In addition to marginal productivity of capital, it is the interaction of capital endowments interacted with (increasing) trade openness that may determine the “competitive” advantage of countries in more or less polluting activities. Since pollution intensive goods are relatively more capital intensive, the factor endowment effects will be likely to cause a reallocation from south to north countries, whose exports will become more and more pollution intensive. In general the mixed evidence could be explained by the fact that we do not expect to see a unique trade environment relationship across all countries. In fact, there is also the issue of environmental policy influence and relative income to take into account. Environmental policy enters the Heckscher Ohlin trade model framework as a factor if we define it as an endowment of pollution permits, relatively more abundant, it is possible to assume, in developing countries (Dietzenbacher and Mukhopadhyay, 2006). Thus, along a path of increasing trade liberalization, or trade openness (Cole, 2003; Costantini and Monni, 2006), various effects play their role according to the Ricardian and Heckscher Ohlin Theories of competitive advantages. Copeland and Taylor (2001) suggest that for industrialised countries more stringent policies and endowment effects of capital may cancel each other out, the first favouring less polluting activities in the country and delocalization of pollution, the second supporting, given relative abundance of capital intensive, though we should be aware of the possibility of well known Leontief paradox (Pasinetti, 1983). Some authors recently even suggested that, according to the pollution haven hypothesis, a “green Leontief” paradox may occur, with developing countries environmentally gaining from extra trade, being extra exports less pollution intensive than extra imports, instead of losing according to the pollution haven hypothesis (Dietzenbacher and Mukhopadhyay, 2006). This is not necessarily a paradox but the prevalence of capital endowments factors on effects of relative policy stringency and relative income.

In this paper the focus is on a within country sector analyses, thus the above reasoning, though important as scenery, should be adapted. We exploit sectoral data on capital stocks to verify whether the emission-value added relationship is confirmed by exploiting the slightly different heterogeneity, across sectors, of capital endowments. Though capital stocks and value added are highly correlated and cannot conceptually fit in the same specification as in some cross country studies, capital related heterogeneity may somewhat differ (see table 2b) and thus provide additional insights to the analyses and it has never been investigated so far. We expect that in most cases the EKC evidence is driven, behind the main and usually observed dynamic of VA/GDP as economic driver, by capital stock endowments and accumulation over time. Trade openness is used as a control factor for estimated (EKC) trends. The specific hypothesis on its role should be adapted in a cross-sector environment, with respect to a cross-country framework where we compare industries and developing countries with respect their comparative advantages. Here, a positive (negative) significant link with emissions per employee could mean that increasing trade openness over time and/or higher trade openness for some sectors decreases (increases) sector

“environmental productivity” (calculated on employees). As commented above, capital stock-related drivers and policy stringency drivers, heterogeneous by sectors, may explain the eventual observed sign of the relationship between emission and trade openness. Analyses will in any case be carried out for all cases in aggregate and the considered macros sector level (industry, manufacturing and services).

4. Empirical outcomes

We test the EKC hypothesis for nine different emissions (see par. 3). As discussed above, we primarily test whether the relationship between emission per employee and value added per employee is consistent either with a linear link or an inverted U shape, or, then, with a cubic trend. The results are then verified by exploiting data on the sectoral stock of capital per employee. Finally, the role of trade openness is analysed; the link of such a variable with emission per employee and the robustness of previous outcomes to its inclusion are scrutinised. As far as the econometrics of panel data is concerned, in most cases, the fixed effects specification³⁰ 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.

We now present and comment on empirical results by sub-dividing between GHGs that bring about global environmental costs and are subject to free riding behaviour by countries (CO₂, N₂O and CH₄) and the other (non direct GHGs) air emissions, most of which are associated to mainly local/regional externality effects³¹. This distinction is maintained, for easing the reader and for its conceptual relevancy, for the three sections: the analysis of EKC with regard value added at aggregate (§4.1) and sectoral level (§4.2), the analysis that exploits capital stocks, at both aggregate and sectoral level (§4.3). The role of trade openness is briefly commented on in §4.4. For brevity, only estimates concerning value added are shown in tables. Comments are provided for regression using capital stocks and trade openness as additional variable. Regression results are available upon request. The section concludes (§4.5) with the evidence provided by the provincial based dataset, that is complementary, since it exploits geographically disaggregated data for the economy as a whole thus extending the scope of production activities disaggregation in terms of emission coverage.

4.1 EKC for NAMEA emissions: empirical evidence on the aggregate of sectors

³⁰ 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).

³¹ We nevertheless underline possible complementarities “in production” at firm or sectoral level between GHGs and other air emissions. EEA (2004, p.64) recognizes that “ many measures to reduce emissions of GHGs reduce air pollutants as well. Implementation of the Kyoto protocol is expected to result in lower cost of air pollution abatement in Europe”. This “complementarity in production”, that is a technologically-based positive correlation between the private fully appropriable and the public good factor, is potentially linked to both/either relationships existing at the level of externalities or product features (e.g. local/global emissions, private or public product/process innovation features; see Kotchen, 2005; Rubbelke, 2003; Loschel and Rubbelke, 2005) and at the level of technologies (e.g. relationships existing among apparently separated technological dynamics: environmental/non-environmental; technological/organisational). Technology and externalities are in any case theoretically interrelated environments; and non convexities in production could be an important element for the joint production of private and public values, depending on fixed costs and technological constraints

4.1.1 Greenhouse gases

An EKC shape is found for CO₂ and CH₄. CO₂ and CH₄ outcomes are similar with and without time effects. Turning points (TPs) are robustly within the range. N₂O is instead associated with a positive linear effect (with elasticity 0.485); the squared specification leads to EKC, but the TP is outside the range. All in all, nevertheless, this is a minor GHG relatively to carbon dioxide and methane.

Overall, then, NAMEA dynamics show EKC evidence at aggregate level. It is worth noting that NAMEA emissions are associated with the share of the economy linked to production activities. The national trends may differ as it includes other components (private and public transports, households, etc.). The aim of the below analysis on provincial data is to provide further evidence concerning the all Italian economy.

4.1.2 Other air emissions

An EKC shape is found for NH₃ and CO. The CO regressions are significant only when time period effects are included and in AR1 specification. Turning points (TPs) are robustly within the range, though for CO are quite polarized in different estimates (Table 2).

Other air emissions present the following evidence. 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. Similar evidence is obtained for PM₁₀ and NMVOC.

To sum up, we may conclude that aggregate evidence regarding GHGs is supporting relatively more the EKC hypotheses if compared to emissions with regional or local impacts. This may be a counterintuitive results with respect to past EKC evidence. We note again that this evidence is peculiar to the generation of emissions by production sectors, not of the entire economy, which includes in addition road transport, heat production and residential heating.

The analysis has shown, at another level of reasoning, that comparisons of baseline LSDV with models including time effects and AR1 (highlights that EKC outcomes may be dependent on the chosen specification).

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 in each sector case, 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 (G-O), Industry (C-F) and manufacturing only (D)³². 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.

4.2.1 GHGs

The evidence is heterogeneous across emissions. In previous aggregate analyses, three out of nine emissions emerged as being associated with an EKC dynamics, while five showed signs of N shapes. Let us analyse what might be the driving forces of those trends at sectoral level. Within the GHGs group of emissions, the CO₂ trend appears to be driven by industry/manufacturing, but not services. Disaggregated evidence for CH₄ confirms that the aggregate picture for EKC is driven by all three macro sectors.

N₂O can be considered to be an outlier. The EKC turning point was outside the observed range. 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.

4.2.2 Other air emissions

As for CO₂ above, the CO trend appears to be driven by industry/manufacturing, but not services. The evidence for NH₃ 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 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, which support delinking occurring in the sector. 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 for some gases, N shapes may lead to new increases in emissions. This is a signal that policy action must take into account

³² 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.

4.3 Emissions and stock of capital dynamics

4.3.1 GHGs

As far as GHGs are concerned, we observe that the capital per employee variable confirm the empirical evidence that we saw above with the value added per employee only for CH₄. For N₂O the overall no EKC evidence is explained by a balancing out of manufacturing (EKC) and other macro sectors. For CO₂ there is no EKC evidence both in the aggregate and in the sub-macro sectors. Services are mainly associated with a U-shaped curve.

4.3.2 Other air emissions

NO_x present EKC evidence in aggregate, confirmed by sector analyses, while for NH₃, NMVOC and PM₁₀ the EKC trend is driven by industry and manufacturing alone (the macro sector services presents an U-shaped curve). CO and SO_x instead present a U shape in the aggregate, driven by services, with industry showing an EKC trend only in the CO case.

Summing up, then, the inclusion of capital dynamics instead of value added not always confirms the previous results. Capital dynamics is strongly correlated with value added but especially in the case of two GHGs, CO₂ and N₂O, the difference in the results obtained with the two alternative drivers appear.

4.4 Trade openness

Trade openness quite interestingly presents a heterogeneous impact on estimated regressions. First, it sometimes influences the base EKC evidence, though we may note that its correlation coefficient with VA (not K) is high³³. Empirical results are different by considering both the emissions and the different productive sectors, especially when we move from all the sectors to industrial or manufacturing sectors only³⁴.

An overview of the empirical results shows that, considering the GHGs, trade openness has a positive and significant effect for CO₂ (industry), N₂O and CH₄ (manufacturing) while in the services it has a negative and significant impact. With regard to the other gases there is a prevalence of negative effect both in the industrial sectors (manufacturing included) and in the services with the exception of NH₃ (positive in industry and manufacturing) and CO (not significant).

Summing up, we may argue that in the case of GHGs the trade openness has a positive effect on the emission per employee in the industrial sectors but the opposite happens in the only two services sectors for which the degree of openness can be considered; in the case of other gases negative and significant effects prevail.

However further research is needed to understand the heterogeneous effect of the trade openness indicator. In fact, several forces, as the capital structure or the institutional frame, can influence the trade openness and its impact; last but not least the specific contribute of import and export respectively on the trade openness indicator has to be investigated too, because it could have a different impact on the emission level.

³³ Despite this, it has to be noted that the regressors used are value added *per employee* in logarithm and squared logarithm and they are not correlated with the trade openness indicator.

³⁴ With regard to the services, a specific consideration have to be done: the trade openness indicator can be obtained only for the services K and O (real estate, ICT, R&D, firm services and other public, social and personal services) but the effect of trade openness is negative, significant and so strong in the GHGs cases that appears to influence the overall effect.

4.5 GHGs and other air 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)³⁵. GHGs show monotonic relationships (CO_2 and N_2O), while CH_4 a robust EKC shape. This is consistent with the Italian situation described by the EEA³⁶.

Other air emissions like NMVOC, CO and PM_{10} , also show inverted U shaped curves, with coherent within-range turning points, despite being quite low (from 8,200 to 12,100€). In the case of NMVOC and CO, the cubic specification shows an inverted-N shape. Nevertheless, other emission trends show an inverted-N shaped relationship (SO_x and NO_x): the delinking reported by EEA statistics for EU is thus confirmed. NH_3 emissions show evidence of a partial EKC, with an inverted-U shape significant in the non-logarithmic specifications only.

Comparing aggregate results, then, it seems plausible to affirm that CO_2 and other GHGs EKC trends (weakly emerging at Italian and EU level, EEA, 2004) are associated with dynamics occurring at productive level, while the economy as a whole is still on a path of, at best, relative delinking, at the left of a turning point. CO confirm previous EKC evidence, while for pollutants like PM_{10} and NMVOC the opposite is true: the present EKC evidence, which confirm EU outcomes on delinking, is probably and plausibly due to dynamics occurring within the transport and household "sectors". The same reasoning applies to SO_x and NO_x , showing a delinking path at national level and N shapes through NAMEA analysis. This may appear counterintuitive. Our evidence shows that main stationery emitters of such substances are not responsible of the EKC path. Or, in other words, they may be responsible but econometric outcomes suggest that N shapes, that is new upturn in the EKC relationship, are likely to characterise present or next future scenarios.

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

³⁵ 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.

³⁶ "One of the main reasons for the overall emissions rise from 1999 to 2000 was a 2.4% increase in CO_2 emissions from electricity and heat production, due in part to an expansion of power generation from fossil fuels, especially coal, in the UK, the EU's second-largest emitter. Another reason was continued growth in greenhouse gas emissions in Greece, Spain, Ireland, Italy and Belgium" (www.eea.europa.eu).

merged panel datasets at the decentralized level, based on sufficiently long times series and rich cross section heterogeneity at both sectoral and provincial level.

The evidence from this type of investigation, in our opinion, is more informative than that from cross country studies which has dominated in the EKC literature so far, with rare exceptions. This does not mean that other ongoing research directions, here surveyed, are less valuable. We stress the necessity of assessing EKC trends using within-country/regional areas disaggregated data in order to provide more valuable food for policy and more informative and rich evidence. The current constraint is the relatively poor, but increasing, availability of such data at sector/geographical level.

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 as expected 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, CO₂, CH₄ and CO, with coherent within range turning points. Thus, main GHGs appear linked to EKC trends.

Nevertheless, other emission trends show a monotonic relationship or, in some cases, an N shaped relationship (SO_x, NO_x, PM₁₀). Aggregate EKC evidence often hides differentiated trends. In fact, 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, as already noted in the literature, (iii) kind of emissions/environmental pressures and, more important here, (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.

In addition, the exploration of EKC dynamics by considering as the main driver the capital stock per employee instead of value added per employee and, as an additional explicative factor, an indicator of the sectoral trade openness provide new insights and contribution for the discussion. However it has to be pointed out that capital stock seems to be a worse explicative factor with respect to the value added, while the trade openness indicator seems to add new original information. Despite the fact that trade openness appears to have a negative effect on emissions in the entire economy, it generally shows a differentiated effect when we consider GHGs and non-

GHGs in the industrial sectors (or only the manufacturing ones) with a prevalence of positive and negative effects respectively.

The evidence arising from the geographically disaggregated dataset is mixed in terms of the EKC hypothesis. Four pollutants (CH_4 , NMVOC, CO and PM_{10}) 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 are needed.

We may summarise the extensive set of analyses at sector and provincial levels by affirming that EKC evidence is more pronounced for GHGs when focusing on productive sectors, while looking at the entire economy changes the picture in some cases, CO_2 among the others. As we expected, aggregate trends hide heterogeneous sector dynamics, with services relatively more associated with delinking paths, though this is not to be taken for granted. Estimates are then robust to the introduction of trade openness which adds some further, still heterogeneous, insights.

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.

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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	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 : 1975,1980,198 5,1990	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

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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 depends 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

Macro-sector		Sector Code	Sector Description
Primary		A	Agriculture
		B	Fishery
Industry	Other industries	CA	Extraction of energy Minerals
		CB	Extraction of non energy Minerals
	Manufacturing industries	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
	Other industries	E	Energy production (electricity, water, gas)
		F	Construction
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, value added, capital stock and trade openness (yearly values): descriptive statistics

Variable	Mean	Min	Max
VA/N	53,10	10,77 (B, 1992)	286,70 (CA, 1997)
K/N	148,26	22,89 (F, 1992)	852,66 (E, 2001)
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 ₂ O/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)
TO	1,07	0 (F, and most services)	8,01 (CA, 2001)

N=employees in terms of equivalent full time jobs (thousands); VA=value added, K= total capital stock (Millions of euro liras 1995); Emissions (tons), TO=Trade openness (import + export /VA), all variables values over 1990-2001, K and TO over 1991-2001.

Table 3. Empirical evidence: testing the EKC hypothesis for sectoral emissions (sectors A-O, 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	PM ₁₀
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	-	-	-	0.103*	0.618***	-	0.228**	-	0.138***
FEM/REM	REM	REM	FEM	FEM	FEM	FEM	FEM	FEM	FEM
Time fixed effects	EKC	Linear form	EKC				EKC	EKC	EKC
AR1	Yes	No	No	Yes	Yes	Yes	Yes	Yes	No
Turning point(s) (VA/N) [§]	90.6-140.5	1803.47	127.47-178.3			120.48	658.04 (Time period effects)	6.08-178.21	
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	348	348	348	348	348	348	348	348	348

Notes: all variables are to be intended in logarithmic forms. 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 Fixed Effects 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.

[§] VA/N: mean 52.86; range 10.77-286.7

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

Sector	Variables	CO ₂ /N	N ₂ O/N	CH ₄ /N	NO _x /N	SO _x /N	NH ₃ /N	NMVOC/N	CO/N	PM ₁₀ /N
Industry N=216 (12*15)	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***
	Shape	N shape	N shape (weak)	Inverted-U shape	N shape	U shape	N shape	Inverted-N shape	N shape	N shape
	VA/N turning points [^]	137.07 (quadratic)	281.57 (quadratic)	138.12	119.56 (quadratic)		156.15 (quadratic)		150.36 (quadratic)	136.02 (quadratic)
Manufacturing (only) N=168 (12*14)	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***
	Shape	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 turning points ^o	86.09 (quadratic)	201.23 (quadratic)	181.14	397.20 (quadratic)		116.29		113.56	
Services N=108 (12 years*9 sectors)	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**	
	Shape	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 turning points ^c	A negative relationship is generally observed over the period								

Notes: all variables are to be intended in logarithmic forms. Value added turning points are estimated for inverted-U shapes. AR and time period LSDV models are generally not estimated given the reduced availability of data in sub samples (reduced degrees of freedom).

[§] Agriculture though relevant is not estimated due to a too small number of observations (only two sub-sectors).

^c VA/N: mean 44.08; range 24.7-98.18

^o VA/N: mean 47.15; range 21.61-203.84

[^] VA/N: mean 61.34; range 21.61-286.7

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

Variables	CO ₂ /Pop		N ₂ O/Pop		CH ₄ /Pop	
VA/Pop	0.372**	0.342*	0.201*	0.271**	13.989***	11.331***
(VA/Pop) ²	-	-	-	-	-0.744***	-0.607***
(VA/Pop) ³	-	-	-	-	-	-
Pop density	-	0.223**	-	-0.490***	-	-1.142***
FEM/REM	REM	REM	REM	REM	FEM	FEM [°]
Turning point (VA/Pop) [§]	-	-	-	-	9.401	9.334
F test and Chi squared prob.	0.047	0.011	0.085	0.000	0.001	0.000
N	285	285	285	285	285	285

Notes: all variables are to be intended in logarithmic forms.

[°] In this case the asymptotic assumptions of the Hausman test are absent.

[§] VA/Pop: mean 9.53; range 8.95-10.08

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

Variables	NO _x /Pop	SO _x /Pop		NH ₃ /Pop	NMVOC/Pop	CO/Pop		PM ₁₀ /Pop
VA/Pop	-510.061**	-2191.7***	-2141.5***	9.677	11.483*	11.94**	13.124***	15.851**
(VA/Pop) ²	54.245**	231.554***	226.416***	-0.502	-0.618**	-0.662**	-0.726***	-0.864***
(VA/Pop) ³	-1.924**	-8.160***	-7.985***	-	-	-	-	-
Pop density	-	-	0.414*	-	-	-	0.115***	-
FEM/REM	REM	REM	REM	REM	REM	REM	REM	FEM
Turning point (VA/Pop) [§]	-	-	-	-	9.29	9.018	9.039	9.173
F test and Chi squared prob.	0.000	0.000	0.000	0.199	0.000	0.000	0.000	0.000
N	285	285	285	285	285	285	285	285

Notes: all variables are to be intended in logarithmic forms.

[§] VA/Pop: mean 9.53; range 8.95-10.08

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