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**Emissions Trends and
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Sector Analyses of De-
coupling/Recoupling on a
1990-2005 Narea**

Giovanni Marin, University of Ferrara
Massimiliano Mazzanti, University of
Ferrara, University of Bologna and Ceris
CNR National Research Council

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By Giovanni Marin, University of Ferrara

Massimiliano Mazzanti, University of Ferrara, University of Bologna and
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Summary

This paper provides new empirical evidence on Environmental Kuznets Curves (EKC) for greenhouse gases (GHGs) and air pollutants at sector level. A panel dataset based on the Italian NAMEA over 1990-2005 is analysed, focusing on both emission efficiency (EKC model) and total emissions (IPAT model). Results show that looking at sector evidence, both decoupling and also eventually re-coupling trends could emerge along the path of economic development. CH₄ is moderately decreasing in recent years, but being a minor gas compared to CO₂, the overall performance on GHGs is not compliant with Kyoto targets, which do not appear to have generated a structural break in the dynamics at least for GHGs. SO_x and NO_x show decreasing patterns, though the shape is affected by some outlier sectors with regard to joint emission-productivity dynamics, and for SO_x exogenous innovation and policy related factors may be the main driving force behind observed reductions. Services tend to present stronger delinking patterns across emissions. Trade expansion validates the pollution haven in some cases, but also show negative signs when only EU₁₅ trade is considered: this may due to technology spillovers and a positive 'race to the top' rather than the bottom among EU₁₅ trade partners (Italy and Germany as the main exporters and trade partner in the EU). Finally, general R&D expenditure show weak correlation with emissions efficiency. EKC and IPAT derived models provide similar conclusions overall; the emission-labour elasticity estimated in the latter is generally different from 1, suggesting that in most cases, and for both services and industry, a scenario characterised by emissions saving technological dynamics. Further research should be directed towards deeper investigation of trade relationship at sector level, increased research into and efforts to produce specific sectoral data on 'environmental innovations', and to verifying the value of heterogeneous panel models capturing sector heterogeneity.

Keywords: Greenhouse Gases, Air Pollutants, NAMEA, Trade Openness, Labour Productivity, EKC, STIRPAT, Delinking

JEL Classification: C23, O4, Q55, Q56

We thank Cesare Costantino, Angelica Tudini and all ISTAT Environmental Accounting Unit in Rome for the excellent work of providing yearly updated NAMEA matrixes and for valuable comments.

Address for correspondence:

Giovanni Marin
University of Ferrara
Department of Economics Institutions and Territory
Via Voltapaletto 11
44100 Ferrara
Italy
E-mail: giovanni.marin@student.unife.it

EMISSIONS TRENDS AND LABOUR PRODUCTIVITY DYNAMICS SECTOR ANALYSES OF DE-COUPLING/RECOUPLING ON A 1990-2005 NAMEA*

Giovanni Marin[♦] & *Massimiliano Mazzanti*[♦]

Abstract

This paper provides new empirical evidence on Environmental Kuznets Curves (EKC) for greenhouse gases (GHGs) and air pollutants at sector level. A panel dataset based on the Italian NAMEA over 1990-2005 is analysed, focusing on both emission efficiency (EKC model) and total emissions (IPAT model). Results show that looking at sector evidence, both decoupling and also eventually re-coupling trends could emerge along the path of economic development. CH₄ is moderately decreasing in recent years, but being a minor gas compared to CO₂, the overall performance on GHGs is not compliant with Kyoto targets, which do not appear to have generated a structural break in the dynamics at least for GHGs. SO_x and NO_x show decreasing patterns, though the shape is affected by some outlier sectors with regard to joint emission-productivity dynamics, and for SO_x exogenous innovation and policy related factors may be the main driving force behind observed reductions. Services tend to present stronger delinking patterns across emissions. Trade expansion validates the pollution haven in some cases, but also show negative signs when only EU₁₅ trade is considered: this may due to technology spillovers and a positive 'race to the top' rather than the bottom among EU₁₅ trade partners (Italy and Germany as the main exporters and trade partner in the EU). Finally, general R&D expenditure show weak correlation with emissions efficiency. EKC and IPAT derived models provide similar conclusions overall; the emission-labour elasticity estimated in the latter is generally different from 1, suggesting that in most cases, and for both services and industry, a scenario characterised by emissions saving technological dynamics. Further research should be directed towards deeper investigation of trade relationship at sector level, increased research into and efforts to produce specific sectoral data on 'environmental innovations', and to verifying the value of heterogeneous panel models capturing sector heterogeneity.

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♦ Corresponding author. University of Ferrara, Italy. E-mail: giovanni.marin@student.unife.it

♦ (1) University of Ferrara, Italy, (2), University of Bologna, Italy, (3) Ceris CNR National Research Council, Milan, Italy.

1. Introduction

Indicators of ‘delinking’ or ‘decoupling’, that is improvements of environmental/resource indicators with respect to economic indicators, are increasingly used to evaluate progress in the use of natural and environmental resources. Delinking trends for industrial materials and energy in advanced countries have been under scrutiny for decades. In the 1990s, research on delinking was extended to air pollutants and greenhouse gases (GHGs, henceforth) emissions. ‘Stylised facts’ were proposed on the relationship between pollution and economic growth which came to be known as the ‘Environmental Kuznets Curve’ (EKC, henceforth), which was based on general reasoning around relative or absolute delinking in income-environment dynamics relationships.

The value of this mainly empirical paper is manifold. First, its originality lies in the very rich NAMEA sector based economic-environmental merged dataset for 1990-2005 (29 branches), which is further merged with data on trade openness for the EU₁₅ and extra-EU₁₅ dimensions, and research and development (R&D) sector data. The quite long dynamics and the high sector heterogeneity of these data allow robust inference on various hypotheses related to the ‘driving forces’ of delinking trends. In this paper, we investigate CO₂, CH₄, SO_x and NO_x. In addition to core evidence on the EKC shape, we test the following hypotheses: (a) whether services and industry have moved along different directions; (b) whether the increasing trends associated with trade openness among the EU₁₅ and non-EU₁₅ countries affect emissions dynamics, following the ‘pollution haven’ debate (Cole 2003, 2004; Cole and Elliott, 2002; Copeland and Taylor, 2004); (c) whether pre-Kyoto and post-Kyoto dynamics show different empirical structures; (d) whether sector R&D plays a role in explaining emissions efficiency. As empirical reference models we use a standard EKC model that measures emissions in relation to employees as an indication of environmental technical efficiency, and a STIRPAT/IPAT model, which uses emissions as the dependent variable, and relaxes the assumptions about unitary elasticity with respect to labour (population), which enters as a driver. The policy relevance of this work lies in: (1) the temporal structural break in pre-Kyoto and post-Kyoto dynamics; and (2) the macro sector (services, industry) level evidence it provides which could help to shape EU policies such as refinements to existing Emission Trading Scheme (ETS), or a new carbon tax for non-industry sectors or small businesses. The use of NAMEA accounting, which is a panel (that consists of a time series of cross-sections) of observations for air pollutants, value added, trade, R&D and employment matched for the same productive branches of the economy (Femia and Panfili, 2005), is a novelty of our study, compared to other international studies on EKC. We use a disaggregation at 29 productive branches and 4 air polluting emissions.

The paper is structured as follows. Section 2 presents the EKC framework and outlines the main methodological and empirical issues. Some of the more recent studies are reviewed in order to define the state of the art and identify areas where value added may be provided. Section 3 presents and discusses our dataset and methodology. Section 4 presents the main findings for GHGs and other air polluting emissions. Section 5 concludes.

2. Economic growth, environmental efficiency and delinking analyses

Our discussion of some of the approaches to studying delinking begins within a simple IPAT model framework. The IPAT model defines environmental impact (I, i.e. atmospheric emissions or waste production) as the (multiplicative) result of the impacts of population level (P), ‘affluence’ (A) measured as 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 P, A and T for an observed change in I over time and/or across countries. For example, it implies that to stabilise or reduce environmental impact (I) as population (P) and affluence (A) increase, technology (T) needs to change.

While the meaning of P and A as drivers of I is clear, T 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 (\$1) of GDP. As a technical coefficient representing the 'resource-use efficiency' of the system (or if the reciprocal GDP/I is considered, 'resource productivity' in terms of GDP), T is an indicator of the average 'state of the technology' in terms of the Impact variable. Changes in T, for a given GDP, reflect a combination of shifts towards sectors with different resource intensities (e.g. from manufacturing to services) and the adoption/diffusion in a given economic structure of techniques with different resource requirements (e.g. 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. $P \bullet A$, which is conceptually equivalent to consumption (Nansai et al., 2007), and T are the main 'control variables' in the system.

Within an IPAT framework, three aspects of 'delinking analysis' and 'EKC analysis' emerge. First, delinking analysis or the separate observation of T may produce ambiguous results. Decreases in the variable I over time are commonly defined as 'absolute decoupling', but might not reflect a delinking process as they say nothing about the role of economic drivers. An environmental Impact growing more slowly than the economic drivers, i.e. a decrease in 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, i.e. population and per capita income.

Second, a delinking process, i.e. a decreasing T, suggests that the economy is more efficient, but offers no explanation of what is driving this process. In its basic accounting formulation, the IPAT framework implicitly assumes that the drivers are all independent variables. This does not of course apply to a dynamic setting. The theory and evidence suggests, that, in general, if T refers to a key resource such as energy, then T can depend on GDP or GDP/P, and *vice versa*. In a dynamic setting, I can be a driver of T as the 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' (Zoboli, 1996). But, 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 (through the re-discovery of the Hicksian 'induced innovation' hypothesis in the environmental field), 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 that also involve dynamic feedbacks, for which economics proposes a set of open interpretations.

Third, EKC analysis addresses some of the above relationships, i.e. between I and GDP or between T and GDP/P, by looking at the direct/indirect 'benefits' and 'costs' of growth in terms of environmental Impact. Even though it may highlight empirical regularities that are of heuristic value, it does not directly provide economic explanations. 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 (or I/GDP) and GDP/P. We note only that if the relationship is between I and GDP, the EKC provides the same information as analysis of T. Furthermore, if I and GDP show

an EKC relationship, then there should also be one evident between T and GDP because, with some exceptions, both P and GDP are increasing over the long run, and delinking must have occurred at some level of GDP. However, in the case of an EKC for T and GDP or GDP/P, it does not necessarily follow that this will also apply to 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 an additional risk. The existence of an EKC could deterministically be 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 growth can be the 'best policy strategy' to reduce environmental Impact.

We now provide a short assessment of some recent contributions in the delinking, structural decomposition and EKC analyses fields. Though our work relies mainly on an EKC-like framework, insights from other fields, such as decomposition analysis, are of interest given our specific and intrinsic sector based flavour.

Empirical evidence supporting an EKC dynamics, or delinking between emissions and income growth, was initially more limited and less robust for CO₂, compared to local emissions and water pollutants (Cole et al., 1997; Bruvold and Medin, 2003). Decoupling of income growth and CO₂ emissions is not (yet) apparent for many important countries (Vollebergh and Kemfert, 2005) and, where delinking is observed, is mostly 'relative' rather than 'absolute' (Fischer Kowalski and Amann, 2001).

The exploitation of geographical and sector disaggregated data, in our opinion, is one of the research lines that may provide major advancements in EKC research, since it goes deeper into the (within-country) dynamics of emissions and economic drivers. An increasingly important research field is the integration of EKC, international trade and technological dynamics associated with the so called 'pollution heaven' hypothesis. Among the recent work in this area, we refer to Copeland and Taylor (2004) for a general overview on all such integrated issues, and to Cole (2003, 2005), Muradian et al., (2002), Cole et al. (2006) for empirical evidence based on the use of aggregated and disaggregated industry datasets.

Structural decomposition analysis (SDA) is another correlated technique for analysing delinking trends and focuses on the sector heterogeneity deriving from extensive use of input-output data. Decomposition analysis is one of the most effective and widely applied tools for investigating the mechanisms influencing energy consumption and emissions and their environmental side-effects. Despite some limitations, decomposition has several strengths one of which is that it provides an aggregate measure that captures energy or emissions efficiency trends. SDA has been applied to a wide range of topics, including demand for energy (e.g. Jacobsen, 2000; Kagawa and Inamura, 2004, 2001) and pollutant emissions (e.g. Casler and Rose, 1998; Wier, 1998).

Among the methodologies employed for decomposing energy and emissions trends, the more prominent are index decomposition analyses (IDA) or techniques, input-output structural decomposition analysis (I-O SDA) and related methods such as growth accounting and shift-share analyses. We comment on some work of interest as general background to our paper.

Jacobsen (2000) performs an I-O SDA for Denmark based on trade factors, for the period 1966-1992. He decomposes the changes in Danish energy consumption for 117 industries into six components and finds that structural factors matter less than final demand and intensity of energy, with the exception of trade factors which show a relevant effect. In fact, structural change in foreign trade patterns can

increase domestic energy demand. In the period observed, the effect of strongly increasing exports relative to imports results in dominance of the export effect and an increase in energy demand.

Wier (1998) explores the anatomy of Danish energy consumption and emissions of CO₂, SO₂ and NO_x emissions. Changes in energy-related emissions between 1966 and 1988 (a 22-year period) are investigated using I-O SDA. The study includes emissions from 117 production sectors and the household sector. Increasing final demand (economic growth) is shown to be the main determinant of changes in emissions (CO₂ emissions increased proportional to energy consumption, NO_x emissions increased relatively more, while SO₂ emissions declined considerably in the period). The decrease in SO₂ emissions was the result of changes in the fuel mix. de Haan (2001) using I-O analysis calculates that the main causes of reductions in pollution can be categorised as eco-efficiency, changes in the production structure, changes in the demand structure, changes in demand volume. He finds that scale effects are not compensated for by eco efficiency gains, and the reductions resulting from the other two factors are negligible, which resulted in a 20% net increase in CO₂ emissions in the Netherlands for 1987-1998. This study confirms the complementarity and increased value in terms of the information to be derived from decomposition analysis compared to delinking studies, which calculate the income-environment dynamic elasticity and the drivers of delinking using NAMEA data (Mazzanti et al., 2008a,b).

Kagawa and Inamura (2001) applied an I-O SDA model to identify the sources of changes in the energy demand structure, the non-energy input structure, the non-energy product mix and the non-energy final demand of embodied energy requirements in Japan, for 1985 to 1990. The authors used a hybrid rectangular I-O model (HRIO) expressed in both monetary and physical terms. The results show that total energy requirements increased mainly because of changes in the non-energy final demand, while product mix changes had the effect of energy saving.

We conclude this section with some policy-oriented reasoning. Taking account of national dynamics is highly relevant when reasoning around the underlying dynamics of emissions and related policy implementation and policy effectiveness. The value of country based delinking evidence is high, and NAMEA structured studies could provide great value added for the policy arena as well as contributing to the EKC economic debate (List and Gallet, 1999). Some stylised facts might help. Concerning GHGs, mainly CO₂ and other air polluting emissions, the empirical literature discussed above and the general evidence (EEA, 2004a) indicate the emergence of at least a relative but also an absolute decoupling at EU level. Acidifying pollutants, ozone precursors, fine particulates and particulate precursors all decrease; however, despite this partially positive evidence, reductions are largely heterogeneous by country and sectors/economic activities. We thus argue that specific in depth country evidence would be helpful to inform both national policies and, e.g. the core Clean Air For Europe (CAFE) programme, and the implementation of the EU ETS and its modification.

3. Empirical model and data sources

3.1 Models and research hypotheses

3.1.1 EKC oriented specifications

We test two kinds of models: the first uses the EKC framework as a reference (Mazzanti et al., 2008a,b for a similar formulation); the second is a modified STIRPAT model.¹

We reformulate the EKC relationship to exploit the sector-level disaggregation of the NAMEA matrix. This framework means we lose standard demographic and income information, but allows us to take

¹ STIRPAT is ‘Stochastic Impacts by Regressions on Population, Affluence and Technology’.

advantage of insights on economic and environmental efficiencies in the production process. Equation (1) shows the EKC based empirical model:

$$(1) \ln(E_{it} / L_{it}) = \beta_{0i} + \beta_1 \text{Kyoto}_{0,1} + \beta_2 \ln(VA_{it} / L_{it}) + \beta_3 [\ln(VA_{it} / L_{it})]^2 + \beta_4 [\ln(VA_{it} / L_{it})]^3 + \varepsilon_{it}$$

In equation (1) *environmental technical efficiency*² (emissions/full-time equivalent jobs) is a function of a third order polynomial equation of labour productivity (in terms of value added per full-time equivalent job), individual (sector) dummy variables (β_{0i}) and a temporal structural break called Kyoto, coded 0 for 1990-1997 and 1 for 1998-2005. Logarithmic forms of the dependent and explanatory variables enables the estimated coefficients to be interpreted as elasticity. We test equation (1) on the whole dataset (29 branches) and then on the separate industry (C, D, E and F) and services (G to O) macro-sectors in order to check whether the average picture differs from that provided by the sub-sample results.

Third order polynomial form allows us to test for non-linearity (normal/inverted U or N shaped curves) in the relationship between E/L and VA/L. A significant cubic specification results in N (or inverted N) shaped curves, while a quadratic one signals U (or inverted U) curve. The choice of polynomial order in the EKC literature is still somewhat controversial. First, an N shaped curve indicates that absolute delinking is followed by a return to a monotonic joint trend of environmental pressures and economic growth (re-coupling) determined by a strong scale effect. Second, many authors (e.g. Stern, 1998) point out that both forms allow environmental pressure tending to an infinite plus or minus, both physically impossible outcomes. Finally, N (or inverted N) shaped curve in a medium-short period perspective may indicate a rather volatile relationship. We believe it is relevant to assess these non-linear shapes in our framework, given that we analyse dynamic relationships across different sectors and pollutants. In addition, even in the presence of pollutants already showing evidence of absolute delinking, the re-coupling hypothesis is worth investigating as a possible (new) state of the world.

Individual effects (β_{0i}) capture the specific features of the branch in terms of average emissions intensity. We estimate these individual effects using a fixed effects model (FEM) (dummy variable regressions) following Wooldridge (2005).³

In addition to the core specification, we design a sort of ‘Kyoto’ structural break by means of a dummy variable that takes the value 1 for the years after 1997, to try to capture the direct or indirect effects of Kyoto Protocol: the direct effects should be GHG emissions reductions in response to policies introduced to meet the Kyoto target; the indirect effects will be related to the anticipatory strategies for future policies on GHGs and, for pollutants, from the ancillary benefits from GHG emissions reductions.⁴ We can state, therefore, in addition to specific Kyoto-related effects, this dummy variable captures temporal variations in emissions linked to various policy effects in the EU and Italian environment, and other temporal changes common to all the branches. The antilog of β_1 can be viewed as the average level of emissions *ceteris paribus* in 1998-2005, with average emissions levels in 1990-1997 equal to 1.

² Intended as emissions on labour (Mazzanti and Zoboli, 2009).

³ “When we cannot consider the observations to be random draws from a large population — for example, if we have data on states or provinces — it often makes sense to think of the β_{0i} as parameters to estimate, in which case we use fixed effects methods” (Wooldridge, 2005, p. 452)

⁴ See EEA (2004b), Markandya and Rübhelke (2003), Pearce (1992, 2000) and Barker and Rosendahl (2000) for in depth analyses of such ancillary benefits.

We first extend the base model by adding two *trade openness indexes*, one for the EU₁₅ and one for the extra-EU₁₅ area. Because of the high level of correlation between the two ‘openness indexes’ (0.796) we analyse them separately to overcome potential collinearity problems. We can then refer to (2) and (3):

$$(2) \quad \ln(E_{it} / L_{it}) = \beta_{0i} + \beta_1 \text{Kyoto}_{0,1} + \beta_2 \ln(VA_{it} / L_{it}) + \beta_3 [\ln(VA_{it} / L_{it})]^2 + \\ + \beta_4 [\ln(VA_{it} / L_{it})]^3 + \beta_5 \ln(TO_{EU15})_{it} + \varepsilon_{it}$$

$$(3) \quad \ln(E_{it} / L_{it}) = \beta_{0i} + \beta_1 \text{Kyoto}_{0,1} + \beta_2 \ln(VA_{it} / L_{it}) + \beta_3 [\ln(VA_{it} / L_{it})]^2 + \\ + \beta_4 [\ln(VA_{it} / L_{it})]^3 + \beta_5 \ln(TO_{EXTRA_EU15})_{it} + \varepsilon_{it}$$

For a review of the theoretical reasoning behind the link between trade openness and emissions growth, we refer among others to Zugravu et al. (2008), Frankel and Rose (2005), Cole (2003, 2004, 2005), Cole and Elliott (2002), Dietzenbacher and Mukhopadhyay (2006) and Mazzanti et al. (2008a,b). The sign of the relationship depends on two potentially conflicting forces: the delocalisation of polluting industries in less developed areas with lax regulation (*pollution haven* effect); and the country specialisation in capital intensive and energy intensive industrial sectors (factor endowment effect). The originality of our empirical exercise is that we are able to disentangle two trade openness dynamics, within EU₁₅ and extra-EU₁₅. We can state here that EU₁₅ openness is not expected to be associated to *pollution haven* effects on the basis of the growing homogeneity of European environmental policies: we can expect then either a not significant or a negative effect on emissions. EU environmental policies explicitly take account of and correct for potential intra-EU unwanted and harmful to the environment displacement of polluting productions in search of lax environmental policies. Such homogeneity, linked to the growing stringency in EU-wide environmental regulations, could result in a high correlation between EU₁₅ openness and the stringency of domestic environmental regulation, with a potential beneficial effect (race-to-the-top) on environmental efficiency. In the contingent case of Italy, the main trade relationship with Germany, a leader in (environmental) technology and standards in the EU, is a relevant anecdotal fact. Communitarian openness, apart from race-to-the-top effects, is related to intra-sector specialisation in response to relative abundance/scarcity of factors (linked to particular environmental pressures) endowment and the spread of environmental efficient technologies.

Extra-EU₁₅ openness instead captures the balance between the factor endowment and *pollution haven* effects: Italy is expected to have a comparative advantage in capital (and then pollution) intensive productions and more stringent environmental regulation relative to the average extra-EU₁₅ trade partners; even relying on the empirical evidence on the issue of environmental effects of trade openness, we can state that no *a priori* expectation about the sign of the relationship between extra-EU₁₅ openness and environmental efficiency is possible.

Finally, we test the effect of R&D/VA, in order to evaluate whether the innovative efforts of enterprises could have a beneficial or negative effect on environmental efficiency. Generally, the adoption of process/product innovations occurs with a delay as a consequence of R&D investments. We use a contemporary R&D/VA ratio because if we use lags we lose too many observations.⁵ If we add R&D, equation (4) becomes the estimation basis.

⁵ The merging of R&D and NAMEA data sources is a worthwhile value added exercise. We are aware that both R&D expenditures are somewhat endogenous with respect to value added in a dynamic scenario. Two stages analysis might be an alternative possibility. R&D is also the input stage of innovation dynamics: data on real innovation adoptions could be more

$$(4) \quad \ln(E_{it} / L_{it}) = \beta_{0i} + \beta_1 Kyoto_{0,1} + \beta_2 \ln(VA_{it} / L_{it}) + \beta_3 [\ln(VA_{it} / L_{it})]^2 + \beta_4 [\ln(VA_{it} / L_{it})]^3 + \beta_5 \ln(R \& D_{it} / VA_{curr_{it}}) + \varepsilon_{it}$$

3.1.2. STIRPAT based specifications

The second category of models is an adaptation of a single-country sector disaggregation of the STIRPAT framework (Dietz and Rosa, 1994; York et al., 2003). The stochastic reformulation of the IPAT formula relaxes the constraint of unitary elasticity between emissions and population, implicit in EKC studies where the dependent variable is the logarithm of per capita pressures on the environment (Martinez-Zarzoso et al. 2007, Cole and Neumayer 2004). This model allows us to investigate explicitly the role of demographic factors in determining environmental pressures and to use a non-relative measure of this pressure as the dependent variable.

We start from a revised IPAT identity,⁶ as described in equations 5-8 below, where the emissions (E) for each branch are the multiplicative result of employment (L), labour productivity (VA/L) and emission intensity of value added (E/VA).

$$(5) \quad E = L * (VA / L) * (E / VA)$$

$$(6) \quad E_{it} = \beta_{0i} * (L_{it})^{\beta_1} * (VA_{it} / L_{it})^{\beta_2} * (E_{it} / VA_{it})^{\beta_3} * e_{it}$$

$$(7) \quad \ln(E_{it}) = \beta_{0i} + \beta_1 \ln(L_{it}) + \beta_2 \ln(VA_{it} / L_{it}) + \beta_3 \ln(E_{it} / VA_{it}) + \ln(e_{it})$$

$$(8) \quad \ln(E_{it}) = \beta_{0i} + \beta_1 \ln(L_{it}) + \beta_2 \ln(VA_{it} / L_{it}) + \varepsilon_{it}$$

$$(9) \quad \ln(E_{it}) = \beta_{0i} + \beta_1 Kyoto_{0,1} + \beta_2 \ln(VA_{it} / L_{it}) + \beta_3 [\ln(VA_{it} / L_{it})]^2 + \beta_4 [\ln(VA_{it} / L_{it})]^3 + \beta_5 \ln(L_{it}) + \beta_6 \ln(L_{it})^2 + \varepsilon_{it}$$

The above stochastic reformulation of equation (5) has some interesting features: it allows separate investigation of the relationship between environmental pressures and employment and uses absolute pressures, which are related more to sustainability issues than relative ones, as the dependent variable. We should stress that in our analysis the focus is on labour not population. This opens the window to complex theory and empirical assessment of labour dynamics associated with technological development, and then with emissions dynamics. For the sake of brevity, we just touch on this issue referring the reader to other streams of the literature. To sum up, the relationship between emissions and employment recalls and is strictly connected to both the (dynamic) relationship between physical capital and labour and the relationship between emissions and physical capital.⁷ This relationship can identify particular effects associated with technological change: emission saving effect, labour saving effect and neutral effect.

effective at an empirical level. More relevant, eco-innovations and environmental R&D should be the focus in this framework. Currently, there are no data from official sources that are at a sufficient disaggregated level; only microeconomic data and evidence on environmental innovation processes are available.

⁶ See Mazzanti et al. (2008a,b).

⁷ We refer to Mazzanti and Zoboli (2009), Stern (2004b), Berndt and Wood (1979); Koetse et al. (2008);

We maintain the third order polynomial form for labour productivity and add the squared term of employment to test for non-linearities. Individual effects, the Kyoto structural break and labour productivity are interpreted similar to the EKC models, the difference being that they now refer to total, not per employee, measures of environmental pressures, which may be more relevant for effective sustainability assessment and provided that policy targets are defined in total terms. The interpretation of the coefficients of employment varies depending on an increasing or decreasing level of labour. In the presence of increasing employment, we observe an emissions saving effect when emissions increase less than proportionally to employment (or even decrease) (elasticity <1), whereas an increase more than proportional of emissions in comparison with employment shows a labour saving effect (elasticity >1). When employment is decreasing the effect linked to each range of elasticity values is inverted.

Similar to the EKC equation, we test the STIRPAT based model on the whole dataset (29 branches) and on the separate industry and services macro-sectors. We add trade openness indexes and the $R\&D/VA$ ratio (equations not shown for brevity): the explanatory role of these variables in the model is the same as in the EKC framework.

3.2 The data

The contribution of our empirical analysis is as follows. Firstly, we assess EKC shapes for four of the GHG⁸ and air pollutant emissions included in NAMEA for Italy, using panel data disaggregated at sector level. We argue that using sector disaggregated panel data improves understanding of the income–environment relationship because it provides rich heterogeneity.

Secondly, we analyse the EKC shapes for total industry and services separately, in order to check whether the average picture differs from the sub-sample results. The sub-sample analysis is suggested by the conceptual perspective of NAMEA (Femia and Panfili, 2005).⁹ In the current work, we are specifically interested in exploring whether the income–environment EKC dynamics of the decreasing (in GDP share) manufacturing sector (more emissions-intensive), and the increasing (in GDP share) services sector (less emissions-intensive), differ. Additional drivers of emissions intensity are then included in order to control the robustness of main specifications and investigate further theoretical hypotheses. The main factors we investigate are trade openness, R&D and some policy-oriented proxies.

We use NAMEA tables for Italy for the period 1990–2005, allowing branch disaggregation at the 2-digit Nace (Ateco) classification level. In the NAMEA tables environmental pressures (for Italian NAMEA air emissions and virgin material withdrawal) and economic data (output, value added,¹⁰ final consumption expenditures and full-time equivalent job) are assigned to the economic branches of resident units or to the household consumption categories directly responsible for environmental and economic phenomena.¹¹ We use only data on economic branches, excluding household consumption

⁸ The main externalities, such as CO₂ and CH₄ for GHGs; SO_x and NO_x for air pollutants. Estimates for PM (particulate matter smaller than 10 microns) are not shown but are available upon request.

⁹ See works by Ike (1999), Vaze (1999), de Haan and Keuning (1996) and Keuning et al. (1999), among others, which provide descriptive and methodological insights on NAMEA for some of the 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 of waste and recycling along with input-output reasoning. We claim that exploiting NAMEA using quantitative methods may, currently and in the future, provide a major contribution to advancements in EKC and policy effectiveness analyses.

¹⁰ Output and value added are both in current prices and in Laspeyres-indexed prices.

¹¹ For an exhaustive overview of environmental accounting system see the so-called ‘SEEA 2003’ (UN et al., 2003).

expenditure and respective environmental pressures, with a disaggregation of 29 branches (2 for the agricultural sector, 18 for industry and 9 for the services sector). The added value of using environmental accounting data comes from the definitional internal coherence and consistency between economic and environmental modules and the possibility of extending the scope of analysis, but still maintaining this coherence and consistence.

We exploit the possibility of extending the basic NAMEA matrix by the addition of foreign trade data: for each branch, import and export of the items directly related to the output of the branch are included (CPAteco classification). Exports correspond to the part of the output of each linked Nace branch sold to non-resident units; imports are CPAteco domestically produced items bought by resident units (including households final and intermediate consumption) supplied by non-resident units. Data on national accounting for foreign trade are available from supply (import) and use (export) tables at the 2-digit CPAteco classification level (51 items) for the period 1995-2004. Istat also produces COEWEB, a very detailed database on Italian foreign trade: time series 1991-2005 of external trade are available at the level of the 4-digit CPAteco classification for A to E capital letters (agricultural sector and industry except F), with a disaggregation for the area (EU₁₅, EU₂₅, EU₂₇ or extra-EU₁₅) of the partner. Unfortunately, we cannot exploit this database consistently because, for privacy protection reasons, Istat do not publish data for branches with less than three units: data related to such branches are also not included in the 4-digit disaggregation or the less detailed disaggregations. However, we use these distinctions between EU₁₅ – extra-EU₁₅ trade as a weighting to split national accounting data. Hereafter, we construct trade openness indicators dividing the sum of imports and exports of every CPAteco category by the value added¹² of the corresponding Nace branch:

$$(10) \quad (TO_{EU15})_{it} = \frac{(X_{EU15})_{it} + (M_{EU15})_{it}}{VA_curr_{it}}$$

$$(11) \quad (TO_{EXTRA_EU15})_{it} = \frac{(X_{EXTRA_EU15})_{it} + (M_{EXTRA_EU15})_{it}}{VA_curr_{it}}$$

where X is export, M is import,¹³ VA_curr is value added at current prices, i is the branch (Nace) or the product (CPAteco) and t is the year between 1995 and 2004, the period of reference for the estimates using these covariates.

We also merge NAMEA tables with ANBERD¹⁴ OECD Database containing R&D expenditures of enterprises for 19 OECD countries, covering the period 1987-2003 (for Italy only 1991-2003, thus the period of reference in below regressions). Enterprises' expenditures are disaggregated according to the ISIC Rev. 3 standard,¹⁵ which is not perfectly compatible with Nace classification because it excludes units belonging to institutional sectors different from private enterprises. We retain only the industrial branches (excluding CA and CB) and exclude services. We use the R&D/VA ratio to derive information on the relative measure of innovative effort of the different branches and to get an index in constant prices. Because of the limited compatibility with national and environmental accounts, the ratio *per se* has a limited meaning but its variations may highlight changes in the relative innovative

¹² Both trade (import and export) and value added are at current prices, giving a inflation-corrected index of openness.

¹³ Import, export and trade openness respectively, with partners inside and outside the EU₁₅ area.

¹⁴ ANBERD is Analytical Business Enterprise Expenditure on Research and Development.

¹⁵ International Standard Industrial Classification (<http://unstats.un.org/unsd/class/family/family2.asp?Cl=2>).

efforts of the enterprises in each industry branch. Figures 1-5 depict the observed dynamics on which we focus.

4. Empirical evidence

We comment on main results of the various empirical analyses focusing first on the two investigated GHGs, and then on regional pollutants such as SO_x and NO_x. Though we do not provide results for PM, we include some comments where necessary.

4.1 Greenhouse gases

4.1.1 EKC specifications

The evidence for CO₂ and CH₄ signals a relative delinking in the cases of the aggregate economy and industry: the elasticity of emissions efficiency with regard to labour productivity in fact is around 0.47-0.49 for CO₂ and 0.77 for CH₄.¹⁶ This outcome is as expected given that Italy is still lagging behind the Kyoto target.¹⁷ Tables 4-5 present the main regressions related to the comments in the text.

For services, estimates show a recoupling trend for CO₂, with a 'low' turning point occurring within the range of observed values. This case highlights the relevance of relying on and studying sector based data. In fact, the recoupling vanishes, becoming an (expected) absolute delinking (negative linear relationship with elasticity -0.61) when we omit sector¹⁸ K (real estate, renting and business activities),¹⁹ a sort of 'outlier' in this²⁰ and other cases which we comment on below. The evidence for CH₄ is similar; the overall evidence is an N shape curve that turns into a bell shape if we exclude K and J.

Focusing on the Kyoto structural break, the two GHGs present quite opposite evidence. If the dummy presents a positive sign for CO₂ driven by industry dynamics, all the other estimated coefficients (for services and methane in industry) are negative. It seems, therefore, that neither the Kyoto emergence nor the 2003 Italian ratification has had significant effects on emissions performances by the main emitters, industrial sectors (76.28% in 2005²¹). Industry has neither massively 'adapted' to the new climate change policy scenario, and even the environmental Italian policy as a whole has somewhat lagged behind other leading countries in terms of policy efforts.²² Future assessments, e.g. of the EU ETS scheme operative since 2005 in the EU (Alberola et al. 2008, 2009; Smith and Swierzbinski, 2007) would provide subjects for further research.²³ The evidence is nevertheless as expected and, in part (in

¹⁶ CH₄ for industry shows an EKC shape with an outside range turning point as shown in Table 5.

¹⁷ Italy is (among EU₁₅) third for total GHGs, 12th for GHGs per capita and 10th for GHGs per GDP and is responsible of 11% of GHGs in the EU₂₇. Current GHGs emissions are 10% higher than the Kyoto target (-6.5% for Italy), and are estimated to be +7.5% to -4.6% in 2010 depending on the measures adopted. German Watch's *Climate change performance index* places Italy 44th in the list of 57 States with major CO₂ emissions, producing 90% of global GHGs.

¹⁸ Actually branch. Hereafter we use the term 'sector' when commenting on a branch sub-sector within a macro sector.

¹⁹ The main fact is that K shows decreasing labour productivity, due to the high growth of employment in services and in some sectors such as K. Employment growth is then higher than value added growth; given that emission efficiency increases, the result is a positive sign captured by panel estimates. Heterogeneous panel models may circumvent this estimation output. This example shows the importance of investigating latent sector dynamics, and the relevance of analysing the driving forces of decoupling and recoupling trends.

²⁰ See Fig. 6 for a graphic representation of the role of K as an outlier in the services macro-sector.

²¹ In this kind of econometric analysis each branch is assigned the same weight, regardless of the contribution to total environmental pressure. Thus, the general figure could derive from the behaviour of branches with low emissions. In order to account for this risk we tested the base models to reduce the datasets to include only branches whose contribution to total emissions was over 5% in 2005. In general, the evidence from these estimates confirms the aggregate results in the specific range of VA/L.

²² The Italian carbon tax proposal of 1999 was never implemented.

²³ In the recent debate over the implementation of ETS in Europe, the Italian government claimed that the end (even if gradual) of the 'grandfathering' system (the assignment of permits with no paying) would damage the competitiveness of

addition to the main sources of private transport and household emissions), a reason for the lack of absolute delinking regarding GHGs in the Italian economy so far.²⁴

Moving on to the results for trade openness and R&D (all estimated regressions omit services), we note that neither trade openness dynamics emerge as significant. This may be due to the compensating and opposite effects (pollution haven and capital abundance) of trade on emissions, an explanation proposed by several authors who also found not (very) significant relationships.²⁵

R&D²⁶ overall is not relevant: a 10% statistical significance emerges only for carbon, with a positive partially counterintuitive sign, which may reflect the weak eco-innovation content of and low environmental expenditure on process innovation dynamics in Italian industries, on average. Economic significance is also low, and the coefficient is negligible. We refer to what we said above about the need for further investigation of the relationship using specific environmental innovation data at sector level.

4.1.2 STIRPAT specifications

In this type of analysis we refer to effects on emissions *per se*, not emissions technical efficiency, as stated. Tables 6-7 sum up the main regressions related to comments in the text. We stress that although similar, we would not expect the EKC and STIRPAT evidence to be very different just because on the first focuses on emissions efficiency and the second on emission levels.

First, we can see that relative delinking is confirmed for carbon. For CH₄, the evidence signals an N shape which depends on CA and DF, two sectors that are to the right of the second TP.

There is another sector specific element that emerges from the aggregate figure. We have highlighted that the recoupling is possibly explained by initially increasing emissions and labour productivity trends, then (after 1997-1998) a decreasing emissions and productivity figure. Thus, it can be seen that the Italian situation is rather idiosyncratic and characterised by productivity slowdown, especially during 2001-2006, a period when aggregate labour productivity decreased by 0.1%²⁷, the only case in the EU, and many sectors witnessed a significant decrease. This new and contingent stylised fact has implications for our reasoning in terms of the income-environment relationship. On the one hand a positive sign of the relationship and a potential recoupling, may depend on a decrease in both emissions and productivity;²⁸ on the other hand, a slowdown may have negative implications for environmental efficiency, by lowering investments in more efficient technology, renewables and other energy saving and emissions saving strategies that need initial investment and are the basis of complementarities rather than trade offs between labour and environmental productivities (Mazzanti and Zoboli, 2009). Further, the economic slowdown in association with higher than (historically)

EU (and particularly Italian) manufacturing sectors. In the preliminary negotiation it obtained exemption from payment of emissions quotas for industrial sectors producing paper (DA), pottery, glass (DI) and steel (DJ). The testing of the EKC model separately for those branches highlights the bad performance of paper (elasticity above unity), a smaller delinking in comparison with the industry for pottery and glass (elasticity < 1 but > 0.5) and a robust absolute delinking for steel. According to this evidence, while an exemption would seem appropriate for paper, its justification for pottery, glass and especially steel is less clear.

²⁴ The slight reduction of CH₄ is more than compensated for by carbon emissions increases.

²⁵ Regarding CH₄, we find a negative sign for TO extra-EU₁₅: the relative weaker role of capital intensity for this gas may be an explanation supporting 'pollution haven' evidence. CH₄ is nevertheless highly sector specific, with sector A being responsible for 41%.

²⁶ The correlation between R&D/VA and VA/L is low: 0.0764. We find that a significant and positive relationship between economic productivity (VA/L) and innovative efforts (R&D/VA) only after the third lag (in years) of the R&D/VA ratio.

²⁷ Using the NAMEA data we observe a reduction from 1999 to 2003 (-4.8%), then an increase from 2003 to 2004 and finally a further decrease in 2005.

²⁸ A sort of potential 'hot air' scenario such as occurred in eastern EU countries in the 1990s.

average oil prices may have created incentives for a re-balancing at the beginning of the century towards coal, as happened in the late seventies in most EU countries.

Looking at the evidence for industry and services, relative and absolute delinking respectively are generally confirmed by the STIRPAT models.

The main evidence from the STIRPAT framework relates to the ‘emissions-labour relationship’, which is implicitly defined in the EKC model. We note first that, on average at least, the employment trend, as in other countries, is decreasing for industry and increasing for services over the period considered. We focus on the specific figures for industry and services which we believe are more relevant than aggregate estimates. For industry, the elasticity is positive (0.5 for carbon and 0.7 for CH₄). For services the evidence is more mixed, although : though observing bell shapes and a, carbon-labour curve are typical presents a majority of most ‘positive’ values,²⁹ and CH₄ for two thirds he methane one 2/3 of ‘negative’ ones.

On the basis of the empirical evidence, in the period considered we can propose a ‘labour-saving’ interpretation: emissions decrease less than employment in industry, which has ‘destroyed’ labour. On the other hand, the employment increases in services tend to be associated with ‘emissions saving’ dynamics. This evidence should hold also for the future when we would expect similar trends, although probably mitigated in terms of its relative size.

Finally, trade openness (coverage 1995-2004) is negatively related to emissions for both GHGs (though the size is negligible for CO₂, and for both EU₁₅ and extra-EU₁₅ trade dynamics). This can be interpreted as the pollution haven effect, which is generally driven by trade openness, being more significant if we focus on emissions rather than emissions efficiency.³⁰ This suggests an area for future research. Given that trade openness in the extra-EU₁₅ has increased since 1999, the higher elasticity we estimate has some serious implications for future scenarios. R&D is again positively but negligibly driving carbon emissions, while for CH₄ the sign of the link is negative, but still economically negligible. All Kyoto-related evidence is confirmed as in para 4.1.1.

4.2 *Air pollutants*

4.2.1 *EKC specifications*

For NO_x and SO_x, which both show sharp decreases since 1990, the EKC related evidence suggests non-linear cubic relationships which are worthy of careful investigation. Tables 8-9 present the main regressions in relation to comments in the text.

For NO_x, similar to the case of CH₄, the features of sectors CA and DF explain the final increasing part of the curve:³¹ Productivity slowdown reasoning is the main phenomenon here. In addition, an EKC shape emerges from the econometric analysis. The estimated SO_x inverted N leaves at the right of the second TP a bunch of few units. A U shape then becomes plausible. The coherence of this evidence with the very sharp decrease in emissions over the last 20 years can be found in the statistically and economically very significant ‘Kyoto break’ factor.³² For example, this seems to capture all the statistical explanatory power in the SO_x industry regression. In other words, we can say that for SO_x

²⁹ The elasticity of the linear relationship is 0.77-0.8.

³⁰ This is not true evidently for the EU. We comment on this evidence (negative sign linking EU₁₅ trade openness and emissions) below for air pollutants.

³¹ See Fig. 7 for a graphic representation of the role of CA and DF as outlier aggregate estimations for NO_x.

³² Very significant for both pollutants, but larger for SO_x. We note that, in line with the work cited in the first part of the paper, GHGs and pollutant reductions are often integrated. Climate change related actions lead to ancillary benefits in terms of local pollutant reductions. The more we shift from end of pipe solutions to integrated process and product environmental innovations, the higher the potential for complementary dividends.

the role played by income dynamics is less relevant for explaining environmental pressures relative to more exogenous factors that are only partly captured here. These include the many regulatory interventions on air pollution by the EU since the early 1980s (e.g. Directive 1980/779/EC substituted by the 1999/30/EC, the Directive 1999/32/EC, the new CAFE (Clean Air for Europe) programme from 2005), and the adoption of end of pipe technologies which are currently the main tool for addressing pollution.

For services, both pollutants show U curves mainly depending on the J and K outlier dynamics, already commented on above for CO₂ and CH₄. In addition, services shows the expected negative linear income-environment dynamics, well beyond the EKC turning point. It remains relevant to assess the extent to which stagnation periods may affect, more or less substantially, the structural trend depicted by the EKC hypothesis.

Trade openness shows negative and significant coefficients that are larger for SO_x. If on the one hand the extra-EU₁₅ related evidence suggests a stronger weight of the ‘pollution haven’ factor relative to endowments, on the side of EU₁₅ trade the motivations may include a number of perspectives. First, increasing trade openness (38% and 65% from 1994 to 2004 respectively for the EU₁₅ and extra-EU₁₅) is associated with a stricter integration in terms of environmental policy, which may explain the good and converging performance of eastern newcomers since the late 1990s (Zurgavu et al., 2008). We can confirm that Italy is a ‘follower’ and a convergent country in terms of environmental policy implementation in the EU context, thus this hypothesis has robust roots. Such convergence may also (have) occur(ed) along pure market dynamics though technological spillovers and increasing technological and organisational environmental standards in order to compete with European leaders. Second, along the path of increasing openness, intra-branch specialisations over time may be favouring more efficient technologies and production processes. This would support increasing Italian specialisation in more environmentally benign sectors and production processes. It is obvious that a structural decomposition analysis would be the best tool for assessing the relevance of these driving forces captured here, at a lower level of sector detail, using econometric techniques that result in more ‘average trends and statistical regularities’.

Finally, it should be noted that SO_x is the only case where R&D emerges as being associated with a statistically negative and economically significant coefficient.³³

4.2.2 *STIRPAT specifications*

As far as the evidence of emissions-labour productivity is concerned, the results confirm the EKC analyses. For NO_x in the aggregate and industry, and SO_x in the aggregate, the same comments on CA and DF apply as above; for services we note again the need for an investigation of sector specificity: sector I explains the N shape, which is transformed into a linear negative dynamics when the sector is omitted and shows a weaker delinking with respect to other sectors. As NO_x emissions are highly dependent on I, the role of this sector emerges as crucial. Tables 10-11 sum up the main regressions with reference to the comments in the text.

³³ If this perhaps seems to conflict with what was said above about end of pipe exogenous effects associated with technological expenditures external to the firm (acquisition of equipment, thus not core R&D), in house or external R&D may be better and primarily targeted towards externalities such as SO_x, embodying some element of privateness in terms of rent appropriability, compared to pure public goods such as GHGs. It remains true that the movement towards integrated process innovations away from end of pipe solutions entails an higher degree of complementarity between GHGs and pollutant reductions.

The link between labour and emissions dynamics is again central in the model. For pollutants, the joint analysis of the estimated coefficients (positive for industry, negative for services, positive in the aggregate) and past recent labour macro-sector trends already noted, suggest an emissions saving dynamics. Over time, the size of the emissions/labour ratio reduces. This links the analysis to the reasoning on capital/labour ratio dynamics over time as a consequence of labour saving, neutral or capital saving innovations (Mazzanti and Zoboli, 2009).

The evidence for Kyoto factors, trade openness and R&D are the same as for the EKC analysis.

NO_x and PM are strongly correlated and overall the evidence is similar. This is the main reason why in this presentation we omit PM estimates. It need only be noted that for PM the EKC and STIRPAT results are very similar and this is coherent with the unitary elasticity we find in the latter model, implicitly assumed in the EKC formulation.

5. Conclusions

This paper provides new empirical evidence on EKC for GHGs and air pollutants at sector level. A panel dataset based on the Italian NAMEA for 1990-2005 was analysed, focusing on emissions efficiency (EKC model) and total emissions (IPAT model). The analysis is highly original since it exploits a very rich and long sector panel NAMEA dataset, merged with compatible data on trade openness distinguished into intra-EU₁₅ and extra-EU₁₅ and sector R&D data, which are not entirely compatible. Various hypotheses can be tested by specifying EKC like and IPAT derived models, looking at how sector specific income-environment dynamics can influence the overall picture. The IPAT model allows investigation of the emissions-labour elasticity, often assumed to be unitary, revealing technological related substitution and complementarity features, which, in the medium-long run, characterise capital, labour and energy inputs. Though the period of reference is a business-as-usual, no-policy time setting for GHGs in Italy, we test whether a structural break in the 1990-2005 series occurred around 1997. The peculiar stagnation/reduction in labour productivity that has affected Italy since 2001 and some sectors in particular, is an interesting economic phenomenon whose investigation allows us to analyse the extent to which a no growth dynamics influences and is correlated to environmental performance.

The results show that looking at sector evidence both decoupling and also eventually re-coupling trends could emerge along the path of economic development. Both the way that the stagnation periods affect environmental performance and contingent sector specificity emerge as relevant explanations of the various U and N shapes. CO₂ seems still to be associated only with relative delinking. CH₄ is moderately decreasing in recent years, but, being a minor gas, overall performance for GHGs is not compliant with the Kyoto targets, which do not appear to have generated a structural break in the dynamics - at least for GHGs. SO_x and NO_x present decreasing patterns, though the shape is affected by some outlier sectors with regard to joint emissions-productivity dynamics in the case of NO_x, and exogenous innovation and policy related factors may be the main driving force behind observed reductions in SO_x. Services tend to show stronger delinking patterns across emissions. Trade expansion validates the pollution haven in some cases, but also shows negative signs when EU₁₅ trade only is considered: this may be due to technology spillovers and a positive 'race to the top' rather than to the bottom among the EU₁₅ trade partners (Italy and Germany as main exporters and also trade partners in the EU). Finally, general R&D expenditures show weak correlation to emissions efficiency.

EKC and IPAT derived models provide similar conclusions overall; the emissions-labour elasticity estimated in the latter is generally different from 1, suggesting in most cases, and for both services and

industry, a scenario characterised by emissions saving technological dynamics (as well as labour saving in relation to GHGs in industry).

The application of heterogeneous panel estimators is a direction for future applied research to assess the extent to which U and N shapes emerge from 'average' trends. Both sector based and country based analyses would benefit from a comparison of homogenous and heterogeneous panel estimations. From a data construction point of view, future research should aim at using environmental R&D and innovation data at sector level; a final and challenging research direction would be to set up trade factors in terms of inter-sector and intra-sector datasets, by exploiting I-O tables and NAMEA or other compatible sources related to trading partners.

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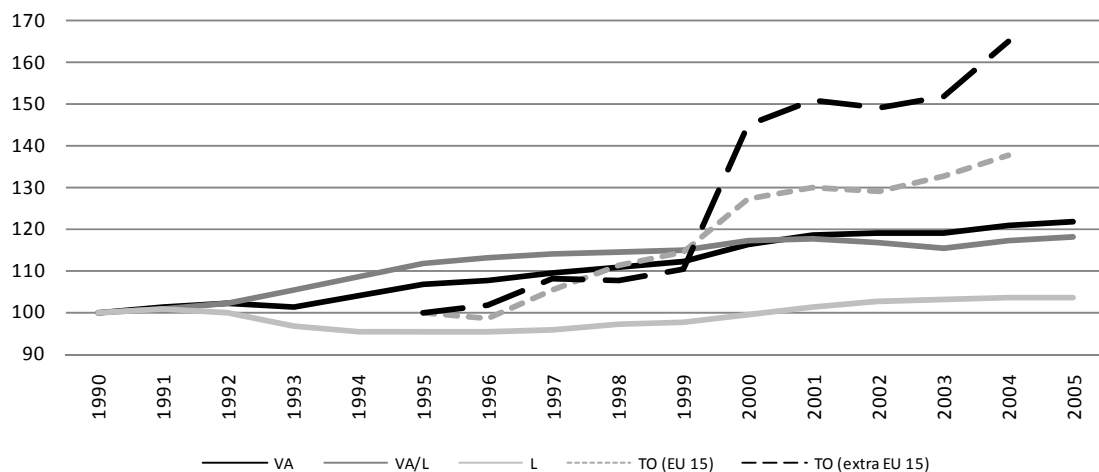


Fig. 1: VA, VA/L, L, TO aggregate (1990=100 for VA, VA/L and L and 1995=100 for TO)

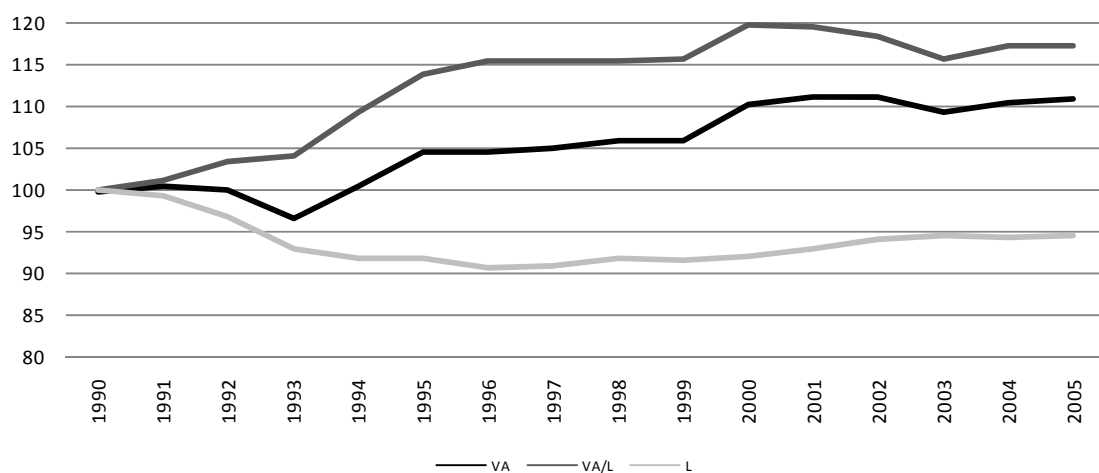


Fig. 2: VA, VA/L, L industry (1990=100)

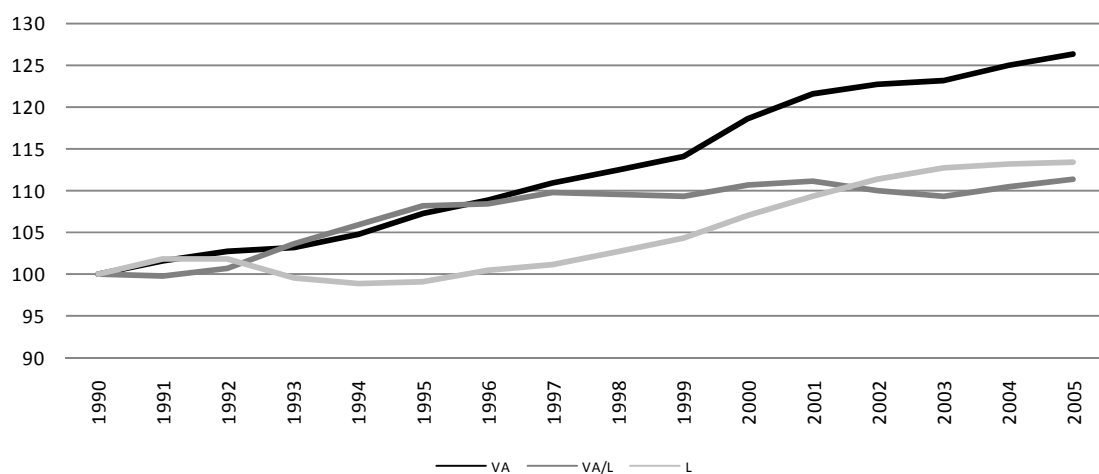


Fig. 3: VA, VA/L, L services (1990=100)

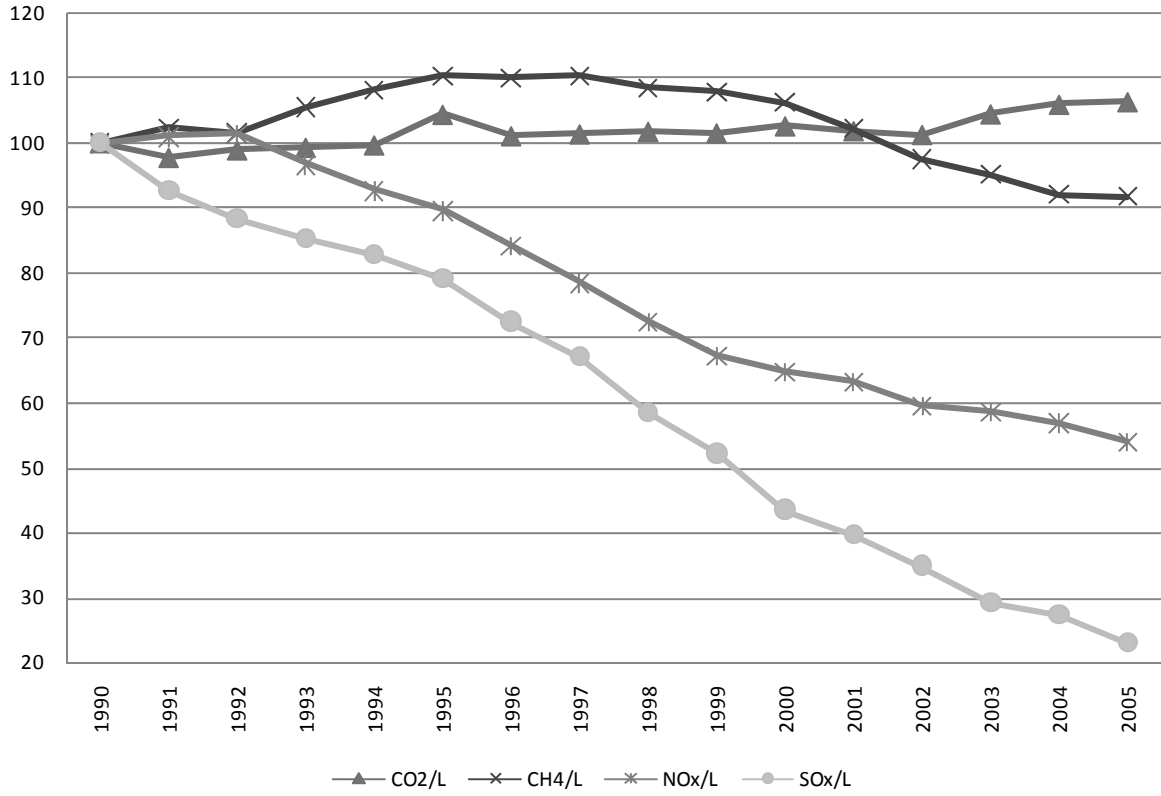


Fig. 4: Emission/L trends (aggregate; 1990=100)

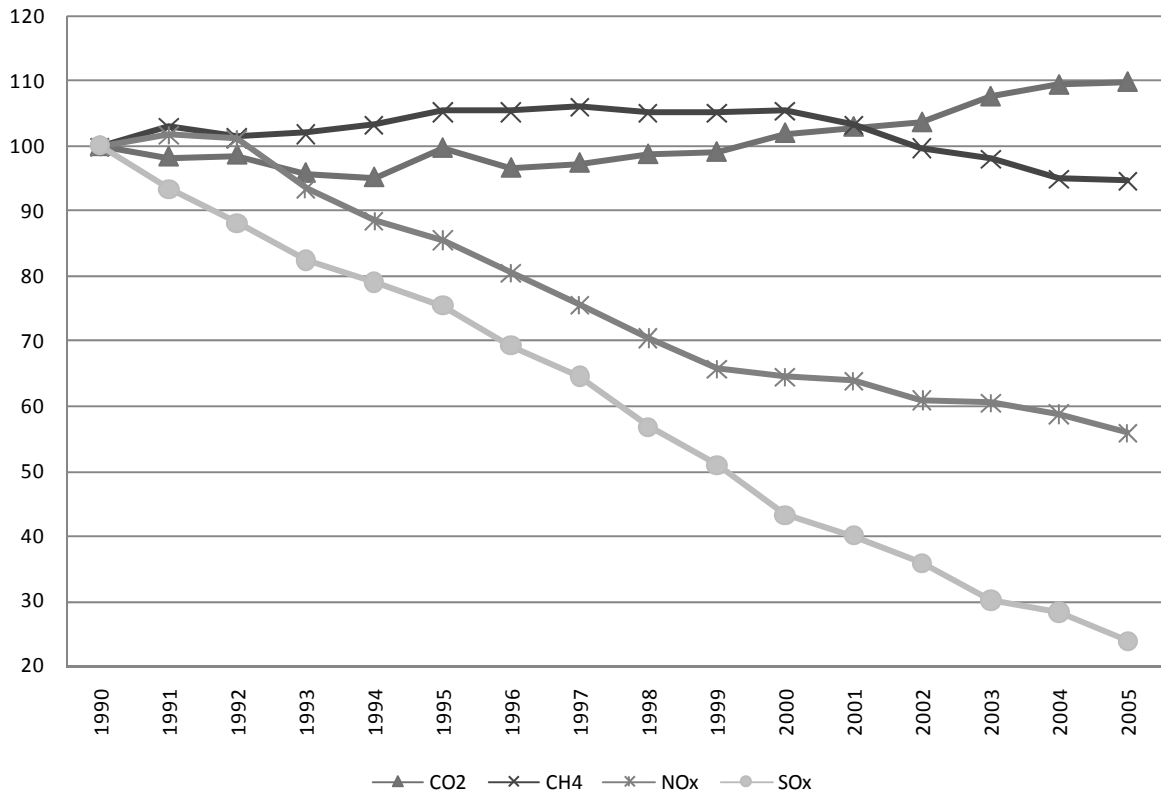


Fig. 5: Emission trends (aggregate; 1990=100)

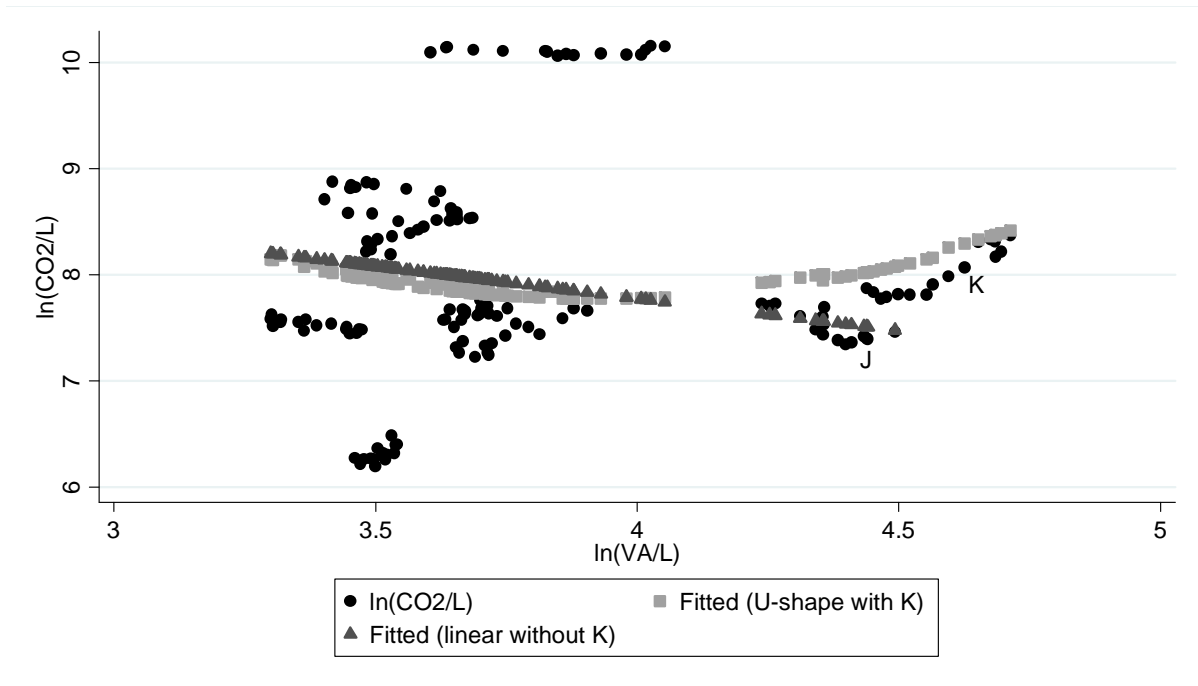


Fig. 6: Outlier K in EKC estimations for CO₂ (services macro-sector)

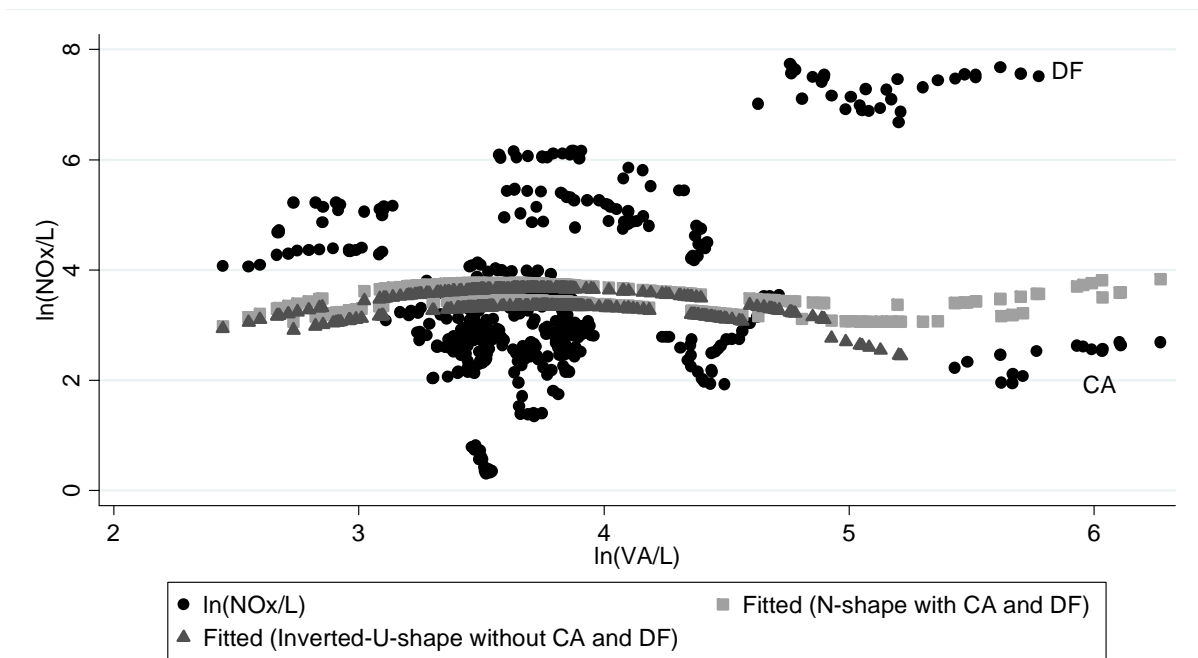


Fig. 7: Outliers CA and DF in EKC estimations for NO_x (aggregate)

Table 1: Nace branches classification

	Nace (Sub-section)	Sector Description
	A	Agriculture
	B	Fishery
Industry	CA	Extraction of energy minerals
	CB	Extraction of non energy minerals
	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
	E	Energy production (electricity, water, gas)
	F	Construction
	Services	G
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

Table 2: Correlation matrix

	ln(VA/L)	ln(L)	ln(TO _{EU15})	ln(TO _{extraEU15})	ln(R&D/VA)
ln(CO ₂)	0.0887	0.0971	-0.1386*	-0.1465*	0.1036**
ln(CH ₄)	0.0134	-0.19	-0.2138*	-0.2829*	-0.0138**
ln(NO _x)	0.2905	0.2157	-0.3233*	-0.5185*	0.0101**
ln(SO _x)	-0.3218	0.132	-0.3641*	-0.5216*	-0.2157**
ln(CO ₂ /L)	0.4161	-0.5348	-0.1485*	-0.0358*	0.1259**
ln(CH ₄ /L)	0.167	-0.4415	-0.2129*	-0.2132*	0.0148**
ln(NO _x /L)	-0.0798	-0.1418	-0.352*	-0.4745*	0.0429**
ln(SO _x /L)	-0.2481	-0.046	-0.3766*	-0.5034*	-0.2039**
ln(VA/L)	1	-0.5003	-0.3698*	-0.1868*	0.0764**
ln(L)	-0.5003	1	0.0282*	-0.1351*	-0.0837**
ln(TO _{EU15})*	-0.3698*	0.0282*	1*	0.7964*	-
ln(TO _{extraEU15})*	-0.1868*	-0.1351*	0.7964*	1*	-
ln(R&D/VA)*	0.0764**	-0.0837**	-	-	1**

* Only for branches A, B, C, D and E

** Only for branches D, E and F

Correlation between panel variables is equal to $corr(x_{it}, y_{it}) = (\beta_1 \beta_2)^{1/2}$, with β_1 and β_2 given by REM estimates of equations $y_{it} = a + \beta_1 x_{it} + v_{2it}$ and $x_{it} = a + \beta_2 y_{it} + v_{2it}$

Table 3: Descriptive statistics

VARIABLE	MIN	MAX	MEAN (overall)	MEDIAN (overall)
<i>WHOLE NAMEA [29 BRANCHES] (1990-2005)</i>				
VA/L	11.51 (A 1990)	528.5 (CA 2000)	62.83	41.51
L	6 (CA 2000, CA 2001)	3660 (G 1991)	780.64	479.5
<i>INDUSTRY [C, D, E, F] (1990-2005)</i>				
VA/L	22.44 (DD 1990)	528.5 (CA 2000)	74.81	45.22
L	6 (CA 2000, CA 2001)	1898 (F 2005)	379.07	266
<i>SERVICES [G, H, I, J, K, L, M, N, O] (1990-2005)</i>				
VA/L	27.11 (H 2004)	111.53 (K 1990)	48.83	39.07
L	588 (J 2000)	3660 (G 1991)	1575.58	1450
<i>TRADE OPENNESS [A, B, C, D, E] (1995-2004)</i>				
VA/L	15.63 (A 1995)	528.5 (CA 2000)	74.69	46.07
L	6 (CA 2000, CA 2001)	1640 (A 1995)	348.62	253
TO EU ₁₅	0.0241 (E 1999)	4.8922 (DF 2003)	1.0334	0.7805
TO extra EU ₁₅	0.0442 (E 1997)	12.796 (DF 2002)	1.3614	0.7368
<i>RESERACH & DEVELOPMENT [D, E, F] (1991-2003)</i>				
VA/L	23.76 (DD 1991)	321.8 (DF 1995)	59.67	44.79
L	24 (DF 2002, DF 2003)	1794 (F 2003)	421.1	279
R&D/VA	0.0408 (F 1992)	179.7654 (DM 1993)	20.999	3.2635

Notes (Tables 4 to 11): 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. All specifications are estimated using FE model; individual fixed effects coefficients are not shown for brevity. Below Kyoto coefficient, between brackets, average emissions in 1998-2005 given 1990-1997 average equal to 100% are shown. *F test* is the joint test of significance on all coefficients whereas *F test fixed effect* is the test of significance on individual fixed effects. TP both for VA/L (two for cubic and one for quadratic specifications) and L are shown: between brackets there is the percentile of each TP. Underlined TP are outside the range of the observations of VA/L or L

Table 4: EKC models for CO₂

	EKC 1	EKC 2	EKC 3	EKC 5
	[aggr]	[ind]	[serv]	[R&D/VA]
	ln(CO₂/L)	ln(CO₂/L)	ln(CO₂/L)	ln(CO₂/L)
$ln(VA/L)$	0.4727***	0.4965***	-7.4279***	0.4726***
$ln(VA/L)^2$			0.9458***	
$ln(VA/L)^3$				
$ln(TO_{EU15})$				
$ln(TO_{extraEU15})$				
$ln(R\&D/VA)$				0.0261*
<i>Kyoto</i>	0.0416*** (104.25%)	0.1098*** (111.6%)	-0.0583** (94.34%)	0.0818*** (108.52%)
<i>Constant</i>	7.4618***	7.9769***	22.4173***	8.0405***
<i>R² (overall)</i>	0.2935	0.449	0.036	0.6309
<i>F test</i>	57.12***	97.32***	15.81***	29.08***
<i>F test fixed effects</i>	1904.22***	1863.46***	1079***	1018.55***
<i>N*T</i>	464	288	144	208
<i>Period</i>	1990-2005	1990-2005	1990-2005	1991-2003
<i>Turning point(s)</i>	-	-	50.7433*** (74)	-
<i>Shape (VA/L)</i>	Linear relationship	Linear relationship	U shape	Linear relationship

Table 5: EKC models for CH₄

	EKC 1	EKC 2	EKC 3	EKC 4a	EKC 4b
	[aggr]	[ind]	[serv]	[TO_{EU15}]	[TO_{extraEU15}]
	ln(CH₄/L)	ln(CH₄/L)	ln(CH₄/L)	ln(CH₄/L)	ln(CH₄/L)
$ln(VA/L)$	0.7745***	1.8288***	80.2449*	TO non sign	-1.7028***
$ln(VA/L)^2$		-0.1085**	-21.585*		0.2078***
$ln(VA/L)^3$			1.9153*		
$ln(TO_{EU15})$					
$ln(TO_{extraEU15})$					-0.2408***
$ln(R\&D/VA)$					
<i>Kyoto</i>	-0.2623*** (76.93%)	-0.0465* (95.46%)	-0.7155*** (48.89%)		0.0654** (106.75%)
<i>Constant</i>	-1.4227***	-3.5908***	-98.0505		5.514***
<i>R² (overall)</i>	0.2274	0.6716	0.0309		0.0843
<i>F test</i>	39.37***	29.72***	58.21***		10.09***
<i>F test fixed effects</i>	1156.84***	1565.26***	1011.3***		1570.47***
<i>N*T</i>	464	288	144		190
<i>Period</i>	1990-2005	1990-2005	1990-2005	1995-2004	1995-2004
<i>Turning point(s)</i>	-	4586.943	29.1941*** (6) 62.7539*** (78)		60.1708*** (76)
<i>Shape (VA/L)</i>	Linear relationship	Inverted-U shape	N shape		U shape

Table 6: STIRPAT models for CO₂

	STIRPAT 1 [aggr]	STIRPAT 2 [ind]	STIRPAT 3 [serv]	STIRPAT 4a [TO _{EU15}]	STIRPAT 4b [TO _{extraEU15}]	STIRPAT 5 [R&D/VA]
	ln(CO ₂)	ln(CO ₂)	ln(CO ₂)	ln(CO ₂)	ln(CO ₂)	ln(CO ₂)
<i>ln(VA/L)</i>	0.1555**	0.3236***	-44.28546**	-3.7014**	-3.665**	0.3106***
<i>ln(VA/L)²</i>			10.8242**	0.9108**	0.9052**	
<i>ln(VA/L)³</i>			-0.8807**	-0.0674**	-0.0671**	
<i>ln(L)</i>	0.2742***	0.5042***	19.9504***	0.4131***	0.3848***	0.3914***
<i>ln(L)²</i>			-1.3123***			
<i>ln(TO_{EU15})</i>				-0.0801**		
<i>ln(TO_{extraEU15})</i>					-0.0857**	
<i>ln(R&D/VA)</i>						0.0219*
<i>Kyoto</i>	0.0536*** (105.51%)	0.0985*** (110.35%)	-0.055* (94.65%)	0.0491*** (105.03%)	0.055*** (105.65%)	0.0759*** (107.89%)
<i>Constant</i>	13.0296***	11.3477***	0.1075	17.6752***	17.7354***	12.1557***
<i>R² (overall)</i>	0.0938	0.1471	0.0812	0.3513	0.3669	0.0151
<i>F test</i>	13.77***	30.31***	13.40***	7.76***	7.79***	12.98***
<i>F test fixed effects</i>	1797.36***	2056.23***	1243.94***	1162.54***	1093.39***	1071.92***
<i>N*T</i>	464	288	144	190	190	208
<i>Period</i>	1990-2005	1990-2005	1990-2005	1995-2004	1995-2004	1991-2003
<i>TP (VA/L)</i>	-	-	51.6548*** (74)	22.1*** (9)	21.6562*** (8)	-
			70.052*** (79)	369.7534*** (97)	373.719*** (97)	
<i>TP (L)</i>	-	-	2000.333*** (84)	-	-	-
<i>Shape (VA/L)</i>	Linear relationship	Linear relationship	Inverted-N shape	Inverted-N shape	Inverted-N shape	Linear relationship

Table 7: STIRPAT models for CH₄

	STIRPAT 1 [aggr]	STIRPAT 2 [ind]	STIRPAT 3 [serv]	STIRPAT 4a [TO _{EU15}]	STIRPAT 4b [TO _{extraEU15}]	STIRPAT 5 [R&D/VA]
	ln(CH ₄)	ln(CH ₄)	ln(CH ₄)	ln(CH ₄)	ln(CH ₄)	ln(CH ₄)
<i>ln(VA/L)</i>	-5.5736**	0.6978***	-1.4912***	-9.175***	-7.8076***	2.0434***
<i>ln(VA/L)²</i>	1.3107**			1.9984***	1.6898**	-0.1405*
<i>ln(VA/L)³</i>	-0.099**			-0.1376***	-0.1164**	
<i>ln(L)</i>	-1.0067***	1.5866***	37.7562***			5.9565***
<i>ln(L)²</i>		-0.0926**	-2.6445***			-0.4585***
<i>ln(TO_{EU15})</i>				-0.1519**		
<i>ln(TO_{extraEU15})</i>					-0.335***	
<i>ln(R&D/VA)</i>						-0.039*
<i>Kyoto</i>	-0.2329*** (79.22%)		-0.5473*** (57.85%)		0.059** (106.07%)	
<i>Constant</i>	21.2267***	-1.20098	-120.8714***	20.9491***	18.9406***	-17.1251***
<i>R² (overall)</i>	0.001	0.0042	0.0181	0.3225	0.1325	0.0019
<i>F test</i>	20.88***	15.37***	76.57***	6.33***	8.28***	8.65***
<i>F test fixed effects</i>	1055.47***	1545.28***	1371.51***	2138.17***	2290.87***	1218.49***
<i>N*T</i>	464	288	144	190	190	208
<i>Period</i>	1990-2005	1990-2005	1990-2005	1995-2004	1995-2004	1991-2003
<i>TP (VA/L)</i>	35.6373*** (36)	-	-	42.1155*** (33)	45.2407*** (45)	1440.685
	190.5869*** (95)			381.101*** (97)	352.0945*** (96)	
<i>TP (L)</i>	-	5233.27	1259.677*** (33)	-	-	661.8836*** (84)
<i>Shape (VA/L)</i>	Inverted-N shape	Linear relationship	Linear relationship	Inverted-N shape	Inverted-N shape	Inverted-U shape

Table 8: EKC models for NOx

	EKC 1	EKC 2	EKC 3	EKC 4a	EKC 4b	EKC 5
	[aggr]	[ind]	[serv]	[TO _{EU15}]	[TO _{extraEU15}]	[R&D/VA]
	ln(NOx/L)	ln(NOx/L)	ln(NOx/L)	ln(NOx/L)	ln(NOx/L)	ln(NOx/L)
<i>ln(VA/L)</i>	10.0681***	11.5742***	-5.6082***	5.9872**	7.1212***	-0.4047***
<i>ln(VA/L)²</i>	-2.3925***	-2.7614***	0.7409***	-1.5026**	-1.7495***	
<i>ln(VA/L)³</i>	0.1829***	0.2104***		0.1195**	0.1361***	
<i>ln(TO_{EU15})</i>				-0.177**		
<i>ln(TO_{extraEU15})</i>					-0.3179***	
<i>ln(R&D/VA)</i>						0.0449*
<i>Kyoto</i>	-0.3102*** (73.33%)	-0.2657*** (76.67%)	-0.4442*** (64.13%)	-0.1344*** (87.42%)	-0.0986*** (90.61%)	-0.2628*** (76.89%)
<i>Constant</i>	-10.0073***	-11.6318**	13.4133***	-3.644	5.3821	5.4869***
<i>R² (overall)</i>	0.0664	0.2302	0.0219	0.0069	0	0.4027
<i>F test</i>	77.55***	41.29***	84.97***	14.81***	18.48***	38.33***
<i>F test fixed effects</i>	687.13***	490.77***	801.01***	438.63***	460.54***	261.86***
<i>N*T</i>	464	288	144	190	190	208
<i>Period</i>	1990-2005	1990-2005	1990-2005	1995-2004	1995-2004	1991-2003
<i>Turning point(s)</i>	34.6481*** (34)	32.4444*** (17)	44.0287*** (67)	26.0667*** (11)	27.873*** (12)	-
	176.9981*** (94)	194.3337*** (91)		167.59*** (90)	188.734*** (92)	
<i>Shape (VA/L)</i>	N shape	N shape	U shape	N shape	N shape	Linear relationship

Table 9: EKC models for SOx

	EKC 1	EKC 2	EKC 3	EKC 4a	EKC 4b	EKC 5
	[aggr]	[ind]	[serv]	[TO _{EU15}]	[TO _{extraEU15}]	[R&D/VA]
	ln(SOx/L)	ln(SOx/L)	ln(SOx/L)	ln(SOx/L)	ln(SOx/L)	ln(SOx/L)
<i>ln(VA/L)</i>	-11.1397***		-19.8059***			-0.4014*
<i>ln(VA/L)²</i>	2.4244***		2.5326***			
<i>ln(VA/L)³</i>	-0.1691***					
<i>ln(TO_{EU15})</i>				-0.5588***		
<i>ln(TO_{extraEU15})</i>					-0.6415***	
<i>ln(R&D/VA)</i>						-0.1427***
<i>Kyoto</i>	-1.224*** (29.41%)	-1.2114*** (29.78%)	-1.0875*** (33.71%)	-0.9168*** (39.98%)	-0.864*** (42.15%)	-0.9923*** (37.07%)
<i>Constant</i>	19.2953***	3.7807***	39.3315***	3.2841***	3.1642***	5.6374***
<i>R² (overall)</i>	0.0745	0.0589	0.0291	0.0355	0.0204	0.0174
<i>F test</i>	218.81***	704.57***	64.84***	209.14***	213.68***	223.3***
<i>F test fixed effects</i>	342.92***	646.16***	127.48***	633.84***	647.78***	248.36***
<i>N*T</i>	464	288	144	190	190	208
<i>Period</i>	1990-2005	1990-2005	1990-2005	1995-2004	1995-2004	1991-2003
<i>Turning point(s)</i>	46.5812*** (65)	-	49.908*** (74)	-	-	-
	303.8811*** (98)					
<i>Shape (VA/L)</i>	Inverted-N shape	No significant relationship	U shape	No significant relationship	No significant relationship	Linear relationship

Table 10: STIRPAT models for NOx

	STIRPAT 1 [aggr]	STIRPAT 2 [ind]	STIRPAT 3 [serv]	STIRPAT 4a [TO _{EU15}]	STIRPAT 4b [TO _{extraEU15}]
	ln(NOx)	ln(NOx)	ln(NOx)	ln(NOx)	ln(NOx)
<i>ln(VA/L)</i>	8.5468***	14.7747***	-101.1291***	6.2669**	6.5561**
<i>ln(VA/L)²</i>	-2.0815***	-3.4499***	25.5436***	-1.5721**	-1.6129**
<i>ln(VA/L)³</i>	0.16***	0.2607***	-2.1457***	0.1253**	0.1253**
<i>ln(L)</i>	0.566***	1.4859***	13.3198**	1.0819***	0.8761***
<i>ln(L)²</i>			-0.9414***		
<i>ln(TO_{EU15})</i>				-0.172**	
<i>ln(TO_{extraEU15})</i>					-0.331***
<i>ln(R&D/VA)</i>					
<i>Kyoto</i>	-0.3033*** (73.84%)	-0.2572*** (77.32%)	-0.3537** (70.21%)	-0.1331*** (87.54%)	-0.099*** (90.58%)
<i>Constant</i>	-4.8665*	-19.2495***	96.383**	-4.4553	-3.9644
<i>R² (overall)</i>	0.174	0.1618	0.1043	0.2226	0.2707
<i>F test</i>	70.24***	57.88***	35.55***	15.08***	18.39***
<i>F test fixed effects</i>	614.9***	496.92***	859.59***	412.89***	424.82***
<i>N*T</i>	464	288	144	190	190
<i>Period</i>	1990-2005	1990-2005	1990-2005	1995-2004	1995-2004
<i>TP (VA/L)</i>	28.1356*** (11)	38.8578*** (32)	43.742*** (63)	26.468*** (11)	27.3207*** (12)
	207.6904*** (95)	174.2916*** (90)	63.9451*** (78)	162.3941*** (90)	194.6497*** (92)
<i>TP (L)</i>	-	-	1181.589*** (28)	-	-
<i>Shape (VA/L)</i>	N shape	N shape	Inverted-N shape	N shape	N shape

Table 11: STIRPAT models for SOx

	STIRPAT 1 [aggr]	STIRPAT 2 [ind]	STIRPAT 3 [serv]	STIRPAT 4a [TO _{EU15}]	STIRPAT 4b [TO _{extraEU15}]	STIRPAT 5 [R&D/VA]
	ln(SOx)	ln(SOx)	ln(SOx)	ln(SOx)	ln(SOx)	ln(SOx)
<i>ln(VA/L)</i>	-2.2639***		-2.1298***	3.8154***	4.0174***	-0.6676***
<i>ln(VA/L)²</i>	0.2273**			-0.4424***	-0.4591***	
<i>ln(VA/L)³</i>						
<i>ln(L)</i>	0.7889***	0.9916***	-2.8852***	-3.6036***	-3.8822***	
<i>ln(L)²</i>				0.5108***	0.5093***	
<i>ln(TO_{EU15})</i>				-0.7244***		
<i>ln(TO_{extraEU15})</i>					-0.8058***	
<i>ln(R&D/VA)</i>						-0.1497***
<i>Kyoto</i>	-1.2064*** (29.93%)	-1.2123*** (29.75%)	-0.7356*** (47.92%)	-0.914*** (40.09%)	-0.8565*** (42.46%)	-1.0019*** (36.72%)
<i>Constant</i>	9.3382***	3.8264**	37.121***	4.5337	5.3881	12.3995***
<i>R² (overall)</i>	0.0457	0.1329	0.05	0.0445	0.0747	0.0167
<i>F test</i>	225.23***	386.51***	64.67***	83.29***	85.13***	242.5***
<i>F test fixed effects</i>	319.81***	609.69***	165.01***	415.78***	422.36***	244.51***
<i>N*T</i>	464	288	144	190	190	208
<i>Period</i>	1990-2005	1990-2005	1990-2005	1995-2004	1995-2004	1991-2003
<i>TP (VA/L)</i>	145.5714* (92)	-	-	74.5703*** (79)	79.4935*** (82)	-
<i>TP (L)</i>	-	-	-	34.0425** (14)	45.2139*** (16)	-
<i>Shape (VA/L)</i>	U shape	No significant relationship	Linear relationship	Inverted-U shape	Inverted-U shape	Linear relationship

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