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Emissions Trends, Labour Productivity Dynamics and Time-Related Events

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Sector Heterogeneous Analyses of Decoupling/Recoupling on a 1990-2006 NAMEA[♣]

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Abstract

This paper provides new empirical evidence on Environmental Kuznets Curves (EKC) for CO_2 and air pollutants at sector level. A panel dataset based on the Italian NAMEA (National Accounting Matrix including Environmental Accounts) over 1990-2006 is analysed, focusing on both emissions 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. The overall performance on here CO_2, is not compliant with Kyoto targets. SOx and NOx show decreasing patterns, though the shape is affected by some outlier sectors with regard to joint emission-productivity dynamics. Services tend to present stronger delinking patterns across emissions than manufacturing. Trade expansion validates the pollution haven in some cases, but also show negative signs when only EU_{15} trade is considered: this may due to technology spillovers and a positive 'race to the top' rather than the bottom among EU_{15} trade partners. General R&D expenditure show weak correlation with emissions efficiency. EKC and IPAT derived models provide similar conclusions overall. Finally, we used SUR estimators (Seemingly Unrelated Regressions) for EKC models on manufacturing to have more efficient panel estimates (constrained model) and to test for slope heterogeneity (unconstrained model): the empirical evidence for CO_2 and SOx emissions suggests that of manufacturing the slope varies across sectors. Further research should be directed towards deeper investigation of trade relationship at sector level and increased research into and efforts to produce specific sectoral data on 'environmental innovations'.

JEL: C23, O4, Q55, Q56

Keywords: NAMEA, trade openness, labour productivity, STIRPAT, SURE

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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 (National Accounting Matrix including Environmental Accounts) sector based economic-environmental dataset for 1990-2006 (29 branches), which is further merged with data on trade openness for the EU_{15} and extra-EU_{15} 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 CO_2, SOx and NOx air emissions. In addition to core evidence on the EKC shape, we test the following hypotheses: (a) whether services and manufacturing have moved along different directions; (b) whether the increasing trends associated with trade openness among the EU_{15} and non-EU_{15} 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) which is the role of the 2002-2006 stagnation in Italian GDP and labour productivity; (e) whether sector R&D plays a role in explaining emissions efficiency; (f) whether there exists heterogeneity across manufacturing branches through SUR (Seemingly Unrelated Regressions) estimates. 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 'productivity growth' (1990-2001) and 'productivity stagnation' (2002-2006) dynamics[1]; and (2) the macro-sector (services and manufacturing) 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 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.

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

[1] We test in addition a sort of 'Kyoto' structural break (post 1997), with possible direct effects on CO_2 and indirect effects on SOx and NOx. Italy ratified Kyoto in 2002. Though the two potential structural breaks are temporally intertwined, they refer to different conceptual hypotheses (c and d above). In the following we will show that empirical outcomes are quite similar, as expected. We will discuss the different latent motivations related to the effects of those two time related 'shocks'.

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 CO_2 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•A•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•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 CO_2 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 CO_2, compared to local emissions and water pollutants (Cole et al., 1997; Bruvoll and Medin, 2003). Decoupling of income growth and CO_2 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, Femia and Marra Campanale, 2010).

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 CO_2, SO_2 and NOx 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 (CO_2 emissions increased proportional to energy consumption, NOx emissions increased relatively more, while SO_2 emissions declined considerably in the period). The decrease in SO_2 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 CO_2 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).

A recent decomposition analysis on Italian NAMEA for the period 1992-2006 is provided by Femia and Marra Campanale (2010). They decompose the changes over time in Italian emissions of GHGs, acidation-related pollutants and tropospheric ozone precursors in variations due to the level of economic output, to the structure of the economic system and to the changes in energy efficiency of production. The increase in output gives rise, all else equal, to an increase in all emissions. For GHGs, this effect is only partially compensated by the structural change of the Italian economy and by more efficient technologies, with an overall increase in emissions. On the other hand, for acidification-related pollutants and troposhperic ozone precursors, structural change and technological progress more than compensate the effect of economic output, with an overall decrease in emissions. They highlight that while emission intensity of energy consumption decreases constantly and without relevant shocks, energy efficiency of

output and the effect due to changes in the mix of fuels are characterized by frequent shocks. Finally, they pass from the aggregate picture to sector-specific analyses which highlight the relevance of compensations among widely differentiated sector dynamics.
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 CO_2, 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, 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.[2]
We reformulate the EKC relationship to exploit the sector-level disaggregation of NAMEA. This framework means we lose standard demographic and income information, but allows us to take advantage of insights on economic and environmental efficiencies in the production process. Equation (1) shows the EKC based empirical model:

$$(1)\ \ln(E_{it} / L_{it}) = \beta_{0\mathrm{i}} + \beta_1 Stagnation_{0,1} + \beta_2 \ln(VA_{it} / L_{it}) + \beta_3 [\ln(VA_{it} / L_{it})]^2 + \varepsilon_{it}$$

In equation (1) environmental technical efficiency[3] (emissions/full-time equivalent jobs) of sector *i* in year *t* is a function of a second 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 'Stagnation', coded 0 for 1990-2001 and 1 for 2002-2006. Logarithmic form of the dependent and explanatory

[2] STIRPAT is 'Stochastic Impacts by Regressions on Population, Affluence and Technology'. See Martinez Zarzoso (2009) who presents some applied analyses deriving from a general model embedding EKC and STIRPAT specifications.
[3] Intended as emissions on labour (Mazzanti and Zoboli, 2009).

variables enables the estimated coefficients to be interpreted as elasticities. We test equation (1) on the whole dataset (29 branches) and then on the separate manufacturing (D) and services (G to O) macro-sectors in order to check whether the average picture differs from that provided by the sub-sample results.

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 recoupling hypothesis (U shape relationship) is worth investigating as a possible (new) state of the world[4].

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 (FE).

In addition to the core specification, we design a 'Stagnation' structural break by means of a dummy variable (valued 1 for the years after 2001). Italian economy experienced a stagnation in productivity in the period 2002-2006 (both at the aggregate level and the macro-sectors level) which could affect environmental-economic productivity relationship in opposite directions. On the one hand, the stagnation in the economic production is expected to result, all else equal, in a (short run) reduction of energy consumption and air emissions. On the other hand, the stagnation of economic productivity might denote and derive from a low efficiency of the production, and could consequentially generate a reduction in eco-innovation investments (and then worsen long run environmental efficiency). Vicious circles in economic environmental performances are the risk in front of the economic system. Moreover, stagnation was associated in the initial phase (2003-2004) to low oil prices, themselves not a stimulus to energy efficiency. When oil prices rose, then, Italy moved as other EU countries to coal. We may then overall expect a negative effect in the GHG performances over this period. Negative performances are also likely for air pollutants.

In addition to the effects linked to the productivity stagnation, this dummy may capture other different temporal related facts: (a) direct[5] (CO_2) and indirect[6] (NOx and SOx) effects of Kyoto Protocol, signed in 1997 an ratified by Italy in 2002; (b) temporal variations in emissions linked to various policy effects in the EU and Italian environment; (c) 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 2002-2006, with average emissions levels in 1990-2001 equal to 1.

We first extend the base model by adding two *trade openness indexes*, one for the EU_{15} and one for the extra-EU_{15} area. Because of the high level of correlation between the two 'openness indexes' (0.6927) we analyse them separately to overcome potential collinearity problems. We can then refer to (2) and (3):

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[4] A U-shape curve could be seen as the right part of a N-shape curve. Egli and Steger (2007) investigate the emergence of recoupling (N-shape curve) in their theoretical model of EKC. They predict that a N-shape curve is the result of a reduction in environmental pressures due to exogenous environmental policies. These policies are implemented when the economy is in the increasing part of the EKC: once the effects of the policies terminate, environmental pressures increase again with income up to the 'natural' turning point. This gives rise to a M-shape curve.

[5] Direct effects should be GHG emissions reductions in response to policies introduced to meet the Kyoto target; 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.

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

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

$$\text{(3)}\quad \begin{aligned} &\ln(E_{it}/L_{it}) = \beta_{0i} + \beta_1 Stagnation_{0,1} + \beta_2 \ln(VA_{it}/L_{it}) + \\ &+ \beta_3 [\ln(VA_{it}/L_{it})]^2 + \beta_4 (TO_{EXTRA\_EU15})_{it} + \varepsilon_{it} \end{aligned}$$

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 Mukhopadhay (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 EU_{15} and extra-EU_{15}. We can state here that EU_{15} 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 EU_{15} 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-EU_{15} 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-EU_{15} 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-EU_{15} openness and environmental efficiency is possible.

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.[7] If we add R&D, equation (4) becomes the estimate basis.

[7] The merging of R&D and NAMEA data sources is a worthwhile value added exercise. We are aware that R&D expenditure 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 effective at an empirical level. More relevant, eco-

$$(4) \quad \begin{aligned} &\ln(E_{it} / L_{it}) = \beta_{0i} + \beta_1 Stagnation_{0,1} + \beta_2 \ln(VA_{it} / L_{it}) + \\ &+ \beta_3 [\ln(VA_{it} / L_{it})]^2 + \beta_4 (R\&D_{it} / VA\_curr_{it}) + \varepsilon_{it} \end{aligned}$$

Finally, we test the base model (see equation (2)) on manufacturing[8] using SUR[9] (Seemingly Unrelated Regressions) instead of Fixed Effect. SUR estimator has several interesting properties. First, constrained[10] SUR estimates are more efficient than FE estimates (Zellner, 1962) and are often implemented to deal with serial correlation and spatial dependence which is likely to occur in sector based panel settings. Efficiency depends positively on the correlation among the residuals of the different equations and negatively on the correlation among the independent variables of the different equations. Second, and linked to the property of efficiency, it is possible to allow for slope heterogeneity across equations (here sectors) with more efficient estimates than simple equation-by-equation OLS estimates.

We estimate both constrained and unconstrained (heterogeneous slopes) SUR and compare these results to the base FE estimates.

For all SUR estimates, Breusch-Pagan test of independence is reported[11]. We also report a test for the aggregation bias (Zellner 1962) which investigates whether the hypothesis of slope heterogeneity (both for labour productivity and 'Stagnation' structural break) is plausible[12].

Figures 8-11 report information on VA/L dynamics and emissions levels for manufacturing branches.

3.1.2. STIRPAT based specifications

The second category of models is an adaptation of the STIRPAT framework to a single-country sector disaggregation (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,[13] 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).

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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.

[8] We used SUR estimator only for manufacturing (14 branches for 17 years) because SUR estimator works only when the number of equations (here, number of branches) is lower or equal to the number observations (here, years).

[9] See Zellner (1962), Zellner (1963) and Zellner, Huang (1962).

[10] By imposing the same slope for all branches and letting the constants differ across branches.

[11] This test regards the contemporaneous correlation of errors across cross-sectional units. The correlation matrix used in this test is the same of that used by the SUR estimator. The null hypothesis is that the correlation matrix of errors is an unitary matrix (Baum, 2001).

[12] The null hypothesis is that the slope is homogeneous across sectors.

[13] See Mazzanti et al. (2008a,b).

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

(6) $E_{it} = \delta_{0i} * (L_{it})^{\delta_1} * (VA_{it}/L_{it})^{\delta_2} * (E_{it}/VA_{it})^{\delta_3} * e_{it}$

(7) $\ln(E_{it}) = \delta_{0i} + \delta_1 \ln(L_{it}) + \delta_2 \ln(\mathrm{VA}_{it}/\mathrm{L}_{it}) + \delta_3 \ln(E_{it}/VA_{it}) + \ln(e_{it})$

(8) $\ln(E_{it}) = \delta_{0i} + \delta_1 \ln(L_{it}) + \delta_2 \ln(\mathrm{VA}_{it}/\mathrm{L}_{it}) + \varepsilon_{it}$[14]

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

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.[15] This relationship can identify particular effects associated with technological change: emission saving effect, labour saving effect and neutral effect.

We maintain the second order polynomial form for labour productivity and add the squared term of employment to test for non-linearities. Individual effects, the ‘Stagnation’ 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 manufacturing 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.

For sake of brevity, we do not report SUR estimates for STIRPAT model, which are available upon request.

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[14] $\delta_3 \ln(E_{it}/VA_{it})$ enters the residuals.

[15] We refer to Mazzanti and Zoboli (2009), Stern (2004), Berndt and Wood (1979), Koetse et al. (2008).

3.2 The data

The contribution of our empirical analysis is as follows. Firstly, we assess EKC shapes for three of the GHG and air pollutant emissions[16] 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 manufacturing 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).[17] 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 1990-2006, with a 2-digit Nace disaggregation level. In the NAMEA tables environmental pressures (for Italian NAMEA air emissions and virgin material withdrawal) and economic data (output, value added,[18] final consumption expenditure 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.[19] We use only data on economic branches, excluding household consumption expenditure and respective environmental pressures, with a disaggregation of 29 branches. 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 consistency.

We exploit the possibility of extending the basic NAMEA matrix by the addition of foreign trade data: for each branch, import and export (within EU_{15} or extra-EU_{15} areas) of the items directly related to the output of the branch are included (CPAteco classification)[20]. We construct trade openness indicators dividing the sum of imports

[16] The main externalities, such as CO_2 for GHGs; SOx and NOx for air pollutants. Estimates for PM (particulate matter smaller than 10 microns) are not shown but are available upon request.

[17] 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.

[18] Output and value added are both in current prices and in Laspeyres-indexed prices.

[19] For an exhaustive overview of environmental accounting system see the so-called 'SEEA 2003' (UN et al., 2003).

[20] 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 for the period 1995-2004. The split between EU_{15} and extra-EU_{15} is made by using as weights data on trade from COEWEB (Istat). We could not use directly COEWEB because, for privacy protection reasons, Istat cannot publish data for branches with less than three units: data related to such branches are also not included in the 4-digit disaggregation of COEWEB or in the less detailed disaggregations.

and exports of every CPAteco category by the value added[21] of the corresponding Nace branch:

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

(11) $$(TO_{EXTRA\_EU15})_{it} = \frac{(X_{EXTRA\_EU15})_{it} + (M_{EXTRA\_EU15})_{it}}{VA\_curr_{it}}$$

where X is export, M is import,[22] *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 ANBERD[23] OECD Database containing R&D expenditure of enterprises for 19 OECD countries, covering the period 1987-2003 (for Italy only 1992-2003, thus the period of reference in below regressions). Enterprises' expenditure are disaggregated according to the ISIC Rev. 3 standard. These data are not perfectly compatible with environmental and national accounts because they exclude units belonging to institutional sectors different from private enterprises and they are the result of surveys and not of direct measurements. We retain only the manufacturing branches. 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 efforts of the enterprises in each manufacturing 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 CO_2 and then on regional pollutants such as SOx and NOx.

4.1 Carbon dioxide

4.1.1 EKC specifications

The evidence for CO_2 signals a relative delinking in the cases of the aggregate economy and manufacturing[24], with an elasticity of emissions efficiency with regard to labour productivity around 0.51 for the aggregate estimate. This outcome is as expected given that Italy is still lagging behind the Kyoto target[25]. Table 5 presents the main regressions related to the comments in the text.

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

[22] Import, export and trade openness respectively, with partners inside and outside the EU_{15} area.

[23] ANBERD is Analytical Business Enterprise Expenditure on Research and Development.

[24] CO_2 for manufacturing shows an EKC shape with a turning point in the last decile of VA/L and an average linear relationship equal to 0.47 (relative delinking).

[25] Italy is (among EU_{15}) third for total GHGs, 12th for GHGs per capita and 10^{th} for GHGs per GDP and is responsible of 11% of GHGs in the EU_{27}. 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 CO_2 emissions, producing 90% of global GHGs.

For services, estimates show a recoupling trend (U shape), 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 -0.58) when we omit sector K (real estate, renting and business activities), [26] a sort of 'outlier' in this[27] and other cases which we comment on below.
The 'Stagnation' structural break presents a positive sign driven by manufacturing dynamics while coefficients for services is negative. However, the economic significance of the estimated coefficients is little. It seems, therefore, that neither the Kyoto emergence nor the 2003 Italian ratification has had significant effects on emissions performance. Manufacturing, which accounts for 37,98% of total direct emissions in 2006, 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[28]. 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[29]. The evidence is nevertheless as expected and, in part (in addition to the main sources of private transport and household emissions), a reason for the lack of absolute delinking regarding CO_2 in the Italian economy so far.
Trade openness (coverage 1995-2004) is negatively related to emissions though the size is negligible and significant only for extra-EU_{15} trade dynamics. This can be interpreted as the pollution haven effect, which is generally driven by trade openness, being more (economically) significant if we focus on emissions rather than emissions efficiency. This suggests an area for future research. Given that trade openness in the extra-EU_{15} has increased since 1999, the elasticity we estimate has some serious implications for future scenarios.
R&D overall is not relevant, which may reflect the weak eco-innovation content of and low environmental expenditure on process innovation dynamics in Italian industries, on average. We here lack data on proper environmental R&D or other environmental innovation proxies. This is a challenge for future research. 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.

[26] 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. This example shows the importance of investigating latent sector dynamics, and the relevance of analysing the driving forces of decoupling and recoupling trends.
[27] See Fig. 6 for a graphic representation of the role of K as an outlier in the services macro-sector.
[28] The Italian carbon tax proposal of 1999 was never implemented.
[29] 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 EU (and particularly Italian) manufacturing sectors. In the preliminary negotiation it obtained exemption from payment of emissions quotas for industrial sectors producing paper (DE), pottery and glass (DI) and steel (DJ). The test of the EKC model separately for those branches highlights the bad performance of paper (elasticity greater than 2), a smaller delinking in comparison with manufacturing for pottery and glass (elasticity just below 1) 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.

Finally, constrained SUR estimates (Table 13) for manufacturing confirm the result of FE estimates. It is worth noting that as expected SUR estimates are more efficient than FE, with lower standard error and 'Stagnation' structural break that becomes significant. This gain in efficiency depends on the high correlation among the disturbances of the different sectors (confirmed by the Breusch-Pagan test of independence).

Unconstrained SUR estimates (Table 11) highlight an high degree of heterogeneity of the slopes across sectors, as confirmed by the test of the aggregation bias. Reasoning around heterogeneity is relevant from both economic and policy oriented perspectives, such as the application of ETS mechanisms. We note that bell-shapes prevail, nevertheless with turning point near or above the maximum observation of VA/L of each branch: sectors that are robustly associated to absolute delinking are DG and DJ, both included in the EU ETS, and quite critical manufacturing sectors as far as pollution effects are concerned. All other sectors show either linear (as DF, highly critical sector for GHG related environmental effects, with regional hot spots, like in Sardinia) or U shaped[30]. The EKC evidence we find in the pooled FEM and constrained SURE may thus derive from the model specification, and it is likely influenced by specificity of the income-environment relationships of high value added sectors.

We observe bad performances for branches DA (Food and beverage), with the worst emissions efficiency/economic productivity dynamics and 'Stagnation' structural break (+20.15%), DE, DI and DM, with a U-shape relationship which denotes a worsening in the performance. Note that two of these branches (DA and DI) obtained exemption from payment of emissions quotas in the framework of the EU-ETS, and such worsening performances may be relevant for the functioning and costs of the ETS for Italian firms[31].

4.1.2 STIRPAT specifications

In this type of analysis we refer to effects on emissions *per se*, not emissions technical efficiency, as stated. Table 6 sums 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. Looking at the evidence for manufacturing 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 manufacturing and increasing for services over the period considered. We focus on the specific figures for manufacturing and services which we believe are more relevant than

[30] The use of heterogeneous estimators can be motivated by the possible heterogeneity bias associated with the use of pooled estimators. As pointed out by Hsiao (2003), if the true model is characterised by heterogeneous intercepts and slopes, estimating a model with individual intercepts but common slopes could produce the false inference that the estimated relation is curvilinear. Empirically, this situation is more likely when the range of the explanatory variables varies across cross-sections. This situation corresponds to our empirical framework where: i) VA presents high variation across sectors, ii) the different units cannot be characterised by a common slope and, consequently, there is a high risk of estimating a false curvilinear relation when using homogeneous estimators.

[31] As far as paper & cardboard (DE) is concerned, we refer to the analysis regarding the implementation of ETS and its innovation potential in the sector in Pontoglio (2010).

aggregate estimates. For manufacturing, the elasticity is positive (0.7). For services the evidence is more mixed: although observing bell shapes, carbon-labour curve presents a majority of 'positive' values (the turning point is in the last decile).
On the basis of the empirical evidence, in the period considered we can propose a 'labour-saving' interpretation: emissions decrease less than employment in manufacturing, 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.
As regards 'Stagnation' structural break, trade openness and R&D, we generally confirm the results of EKC estimates.

4.2 Air pollutants

4.2.1 EKC specifications

For NOx and SOx, which both show sharp decreases since 1990, the EKC related evidence suggests absolute delinking (aggregate) or tendency to recoupling (U shape for manufacturing and services) which are worthy of careful investigation. Tables 8-9 present the main regressions in relation to comments in the text.
As regards NOx, the evidence is of an absolute delinking (inverted-U shape) for the aggregate figure and of a recoupling (U shape) for manufacturing and services.
For both NOx and SOx the feature of sector DF explains the final increasing part of the U shape curve[32]. During the period 1990-2000 both emissions and labour productivity increase while the trend reverts in the period 2001-2006 (decrease of both emissions and productivity). 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%[33], 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;[34] 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) 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. The temporal structural break predicts a *ceteris paribus* reduction in emissions, larger for SOx. This is coherent with the very sharp decrease in emissions over the last 20 years[35].We

[32] If we exclude branch DF, the relationship become linear and negative, denoting an absolute delinking. See Fig. 7 for a graphic representation of the role of DF as outlier in the manufacturing estimations for NOx.

[33] 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.

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

[35] Very significant for both pollutants, but larger for SOx. 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

can say that, mainly for SOx, the role played by exogenous factors is important in explaining the relevant decrease in emissions. These factors 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 CO_2. 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[36] coefficients that are larger for SOx. If on the one hand the extra-EU_{15} related evidence suggests a stronger weight of the 'pollution haven' factor relative to endowments, on the side of EU_{15} trade the motivations may include a number of perspectives. First, increasing trade openness 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'.
R&D expenditure is again not significantly related to (abatement in) emissions, highlighting no complementarities between profit-driven innovation and environmental efficiency. This evidence was mostly expected for GHG, whose 'abatement benefits' are generally not appropriated by firms if not through energy efficiency strategies. The fact that we also find no relation for air pollutants, whose abatement is more strictly linked to generation of appropriable benefits, could be explained by the fact that pollutants are generally abated through end-of-pipe solutions which are not the result of internal R&D.
We finally focus on sector heterogeneity within manufacturing. As for CO_2, constrained SUR estimates (Table 14) confirm the result of FE estimates, with a U shape relationship and more efficient coefficients. Also in these cases, correlation of the disturbances across sectors is significant and the hypothesis of slope homogeneity is rejected (aggregation bias).
Unconstrained SUR estimates for SOx (Table 12) allow highlighting the high degree of (significant) heterogeneity across sectors. We observe mixed evidence: strong absolute delinking for some sectors (DA, DC, DH and DN) and only relative delinking for DF.

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solutions to integrated process and product environmental innovations, the higher the potential for complementary dividends.

[36] Except for EU_{15} for NOx.

The remaining sectors experienced U shape (with most of the observations in the decreasing part of the curve) and inverted-U shape (again, with most observations at the right of the turning point) relationships. 'Stagnation' structural break is more differentiated, with only a positive sign (DI) and *ceteris paribus* reduction ranging from -70.51% (DM) to -27.71% (DF). The two most critical sectors DF and DG presents strong decreases in emission (DF still remaining the worst in levels); structural breaks are significant. Shapes are linear for DF (recall the lowering productivity in the final part) and bell shaped (DG).
Regarding NOx the picture is also very mixed: six cases of bell shaped, five U shapes and even no delinking at all for DE. Then regarding SOx and NOx two main comments emerge: on the one hand the analysis of sector heterogeneity proves to add relevant value to the investigation; pooled estimates hide substantial differences among sectors. Such U shapes derive from averaging over quite different dynamics. On the other hand, the most critical sectors for NOx (DF, DG, DJ and Di above all) present also variegated evidence: DG and DJ associate to bell shaped, while DF (an highlighted outlier) presents a U shape driven by lowering productivity while DI (the worst emitter among all), for which VA increases, shows a U shape deriving from an unstable temporal dynamics of emissions.

4.2.2 STIRPAT specifications

As far as the evidence of emissions-labour productivity is concerned, the results confirm the EKC analyses. For NOx in the aggregate and manufacturing, and SOx 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 NOx 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.
The link between labour and emissions dynamics is again central in the model. For pollutants, the joint analysis of the estimated coefficients (positive for manufacturing, 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 'Stagnation' factors, trade openness and R&D are the same as for the EKC analysis.

5. Conclusions

This paper provides new empirical evidence on EKC for CO_2 and air pollutants at sector level. A panel dataset based on the Italian NAMEA for 1990-2006 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-EU_{15} and extra-EU_{15} 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 1990-2006 series occurred around 2002. The peculiar stagnation/reduction in labour productivity that has affected Italy since 2002 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 non-linear shapes. CO_2 seems still to be associated only with relative delinking. Overall performance for GHGs is not compliant with the Kyoto targets, which do not appear to have generated a structural break in the dynamics. SOx and NOx present decreasing patterns, though the shape is affected by some outlier sectors with regard to joint emissions-productivity dynamics in the case of NOx, and exogenous innovation and policy related factors may be the main driving force behind observed reductions in SOx. Services tend to show stronger delinking patterns across emissions. Trade expansion validates the pollution haven in some cases, but also shows negative signs when EU_{15} 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 EU_{15} trade partners (Italy and Germany as main exporters and also trade partners in the EU). Finally, general R&D expenditure 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 manufacturing, a scenario characterised by emissions saving technological dynamics (as well as labour saving in relation to GHGs in manufacturing).

The application of heterogeneous panel estimators such as unconstrained SUR estimator allows to assess the extent to which non-linear shapes emerge from ‘average’ trends. Average trends, in fact, derive from compensations of heterogeneous and sometime divergent income-environment dynamics, suggesting that aggregation could bring to biases. We found that the relationship between environmental efficiency and labour productivity differs, sometimes substantially, across manufacturing sectors, underlining different eco-innovation opportunities of different branches, different reactions to (policy) events and different structural changes in production and energy processes. Given that sector performances often depend on how production activities are (unevenly in Italy) spread over regions in a country, further highlights may be provided by analysing Regional NAMEA data. Regional idiosyncrasies could explain a large part of the evidence for some sectors and pollutants. Italy is especially characterised by bad performances of energy intensive sectors in the south and islands, and by environmentally bad performances of some industrialised areas in the north (e.g. steel, ceramic, other manufacturing spatially concentrated district branches).

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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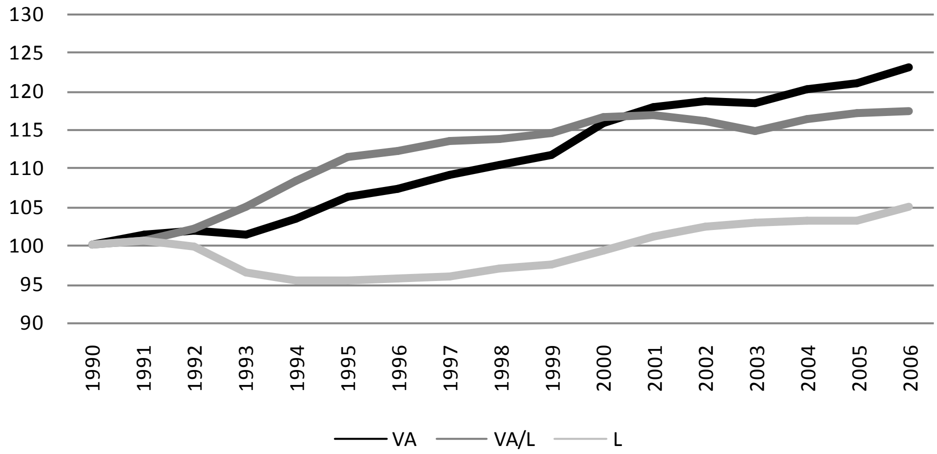

Fig. 1: VA, VA/L, L, TO aggregate (1990=100)

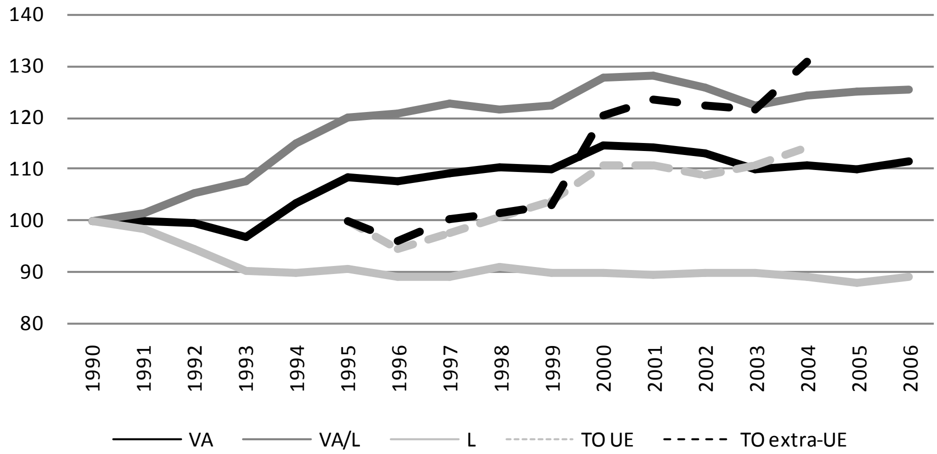

Fig. 2: VA, VA/L, L and TO manufacturing (1990=100 for VA, VA/L and L and 1995=100 for TO)

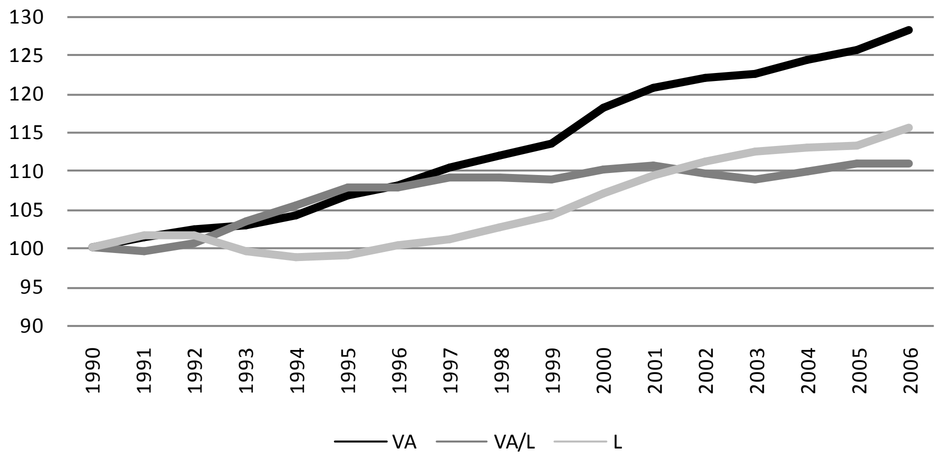

Fig. 3: VA, VA/L, L services (1990=100)

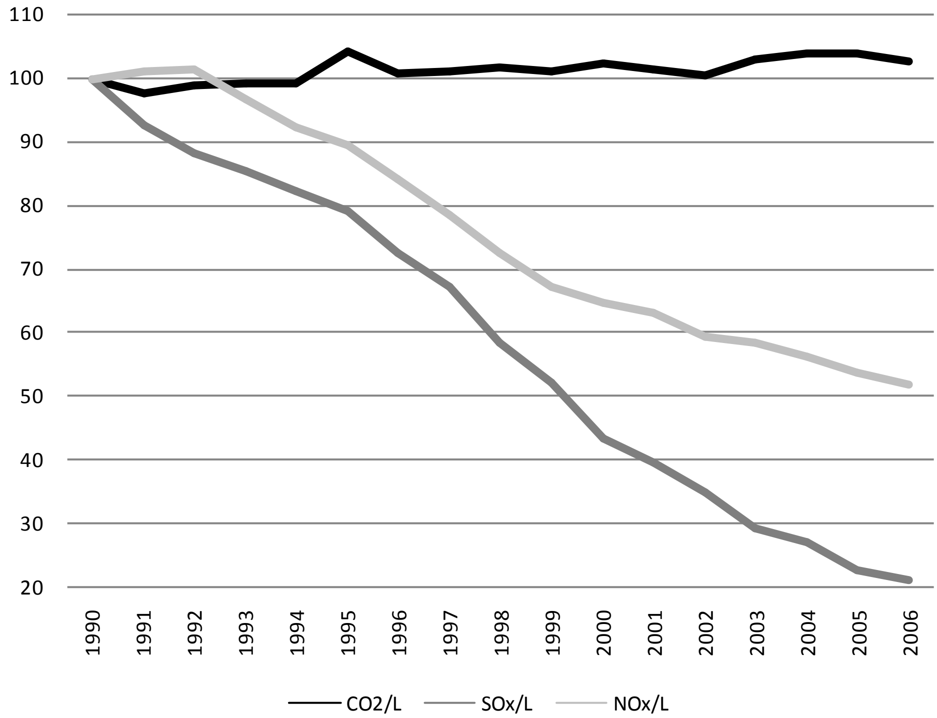

Fig. 4: Emission/L trends (aggregate; 1990=100)

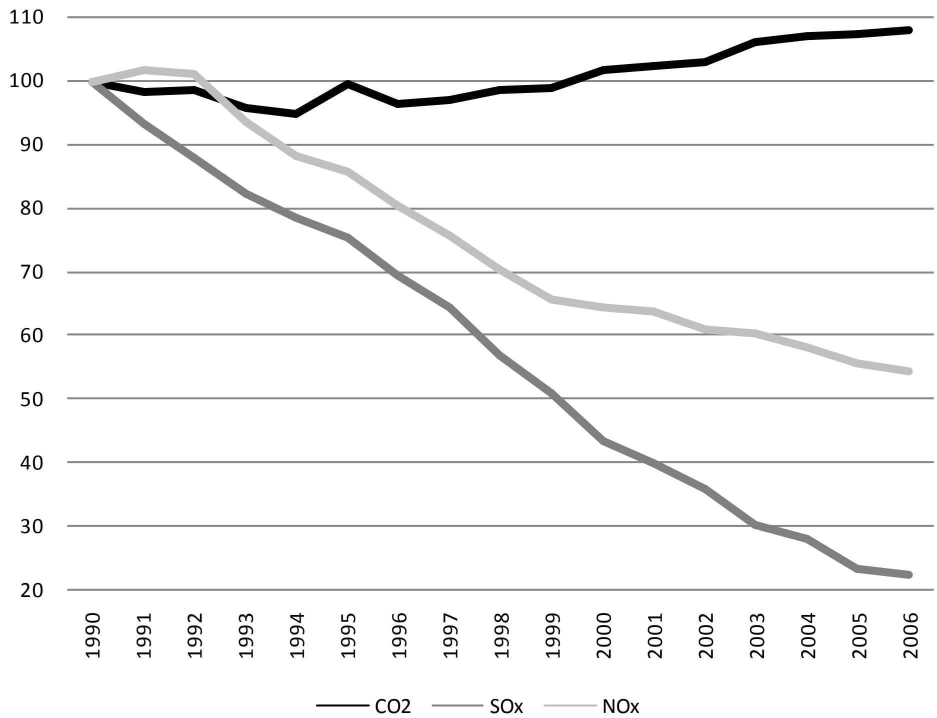

Fig. 5: Emission trends (aggregate; 1990=100)

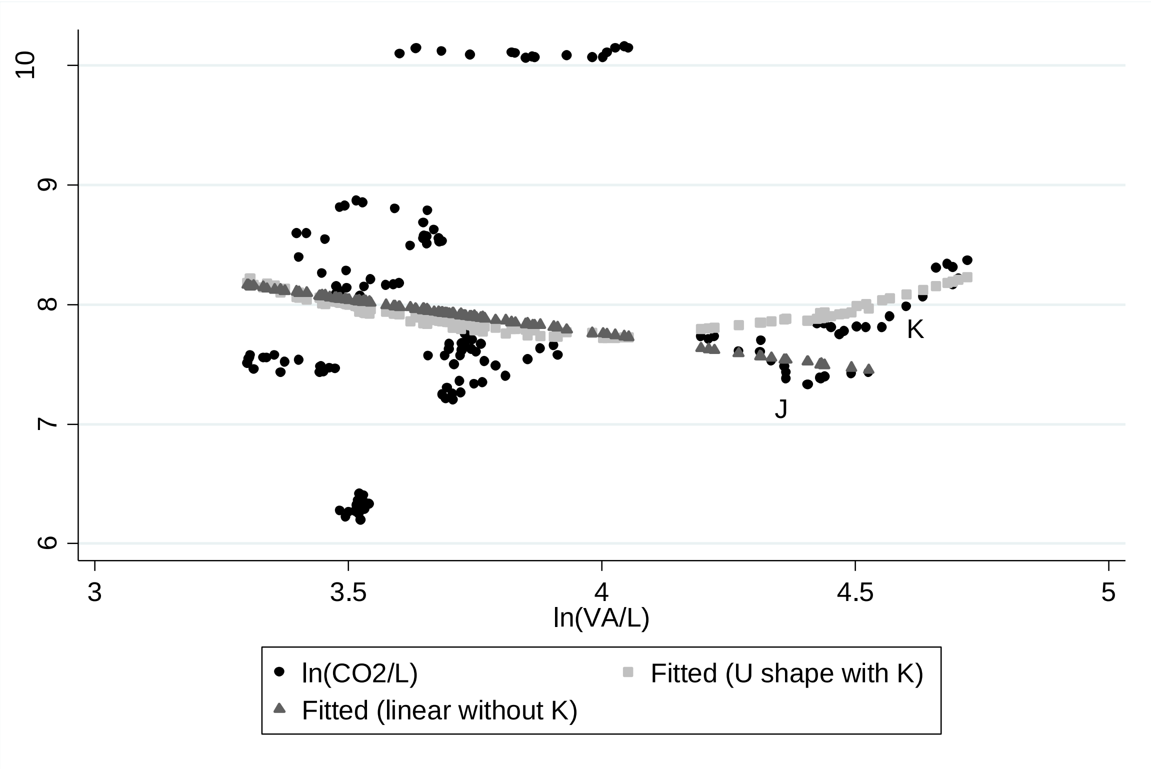

Fig. 6: Outlier K in EKC estimates for CO2 (services macro-sector)

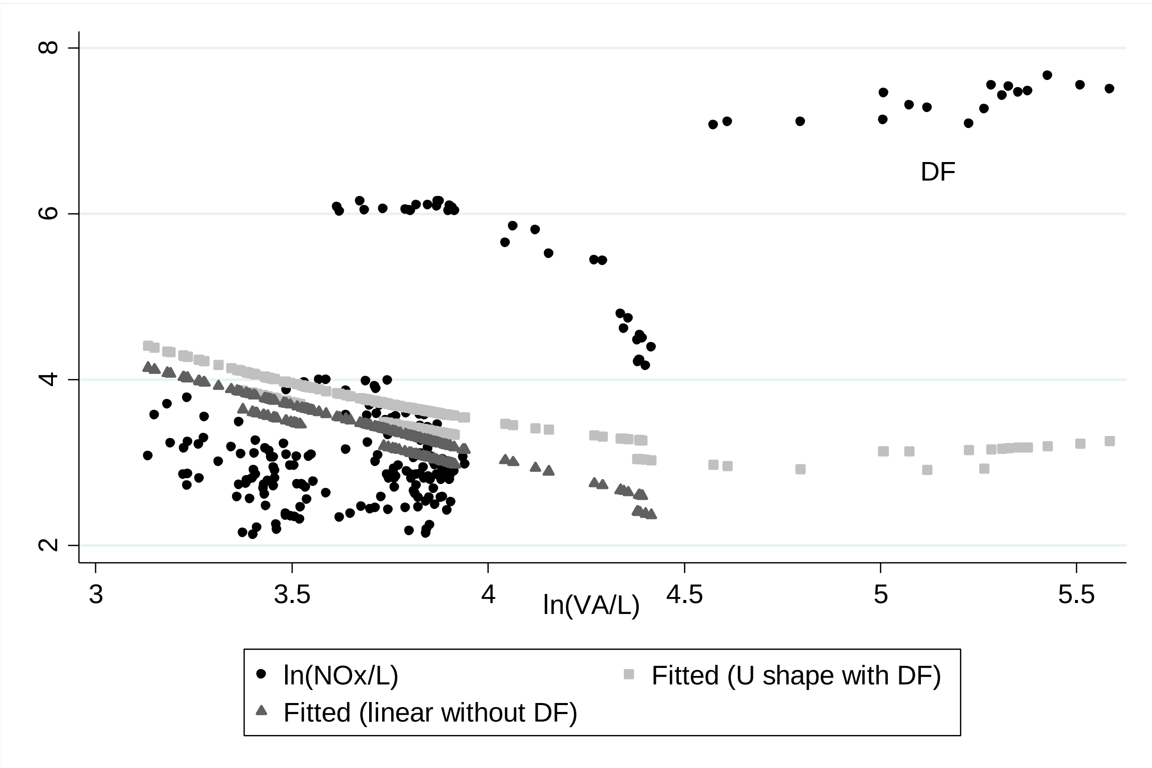

Fig. 7: Outlier DF in EKC estimates for NOx (aggregate)

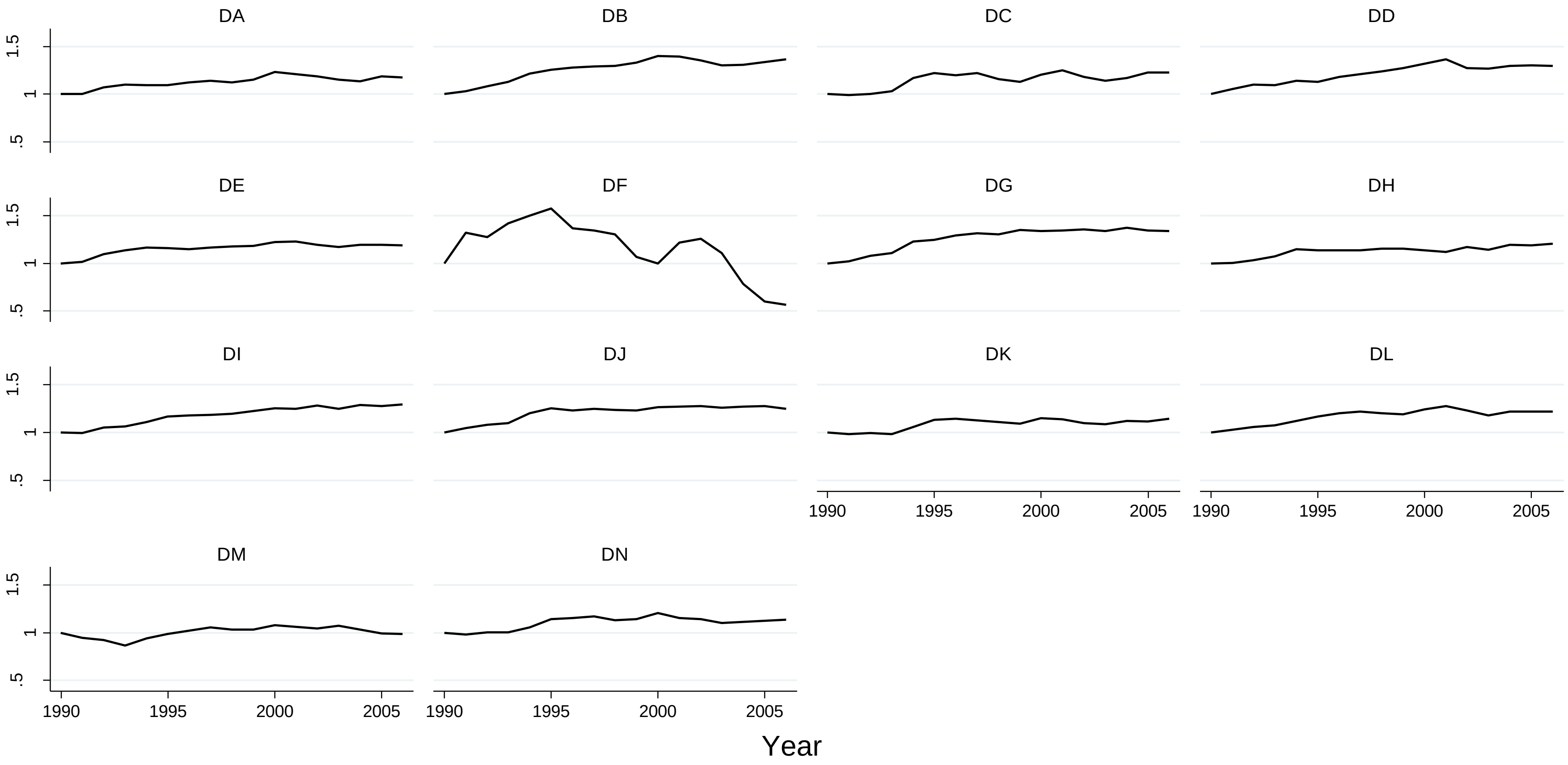

Fig. 8: VA/L (normalized 1990=1) trends (manufacturing)

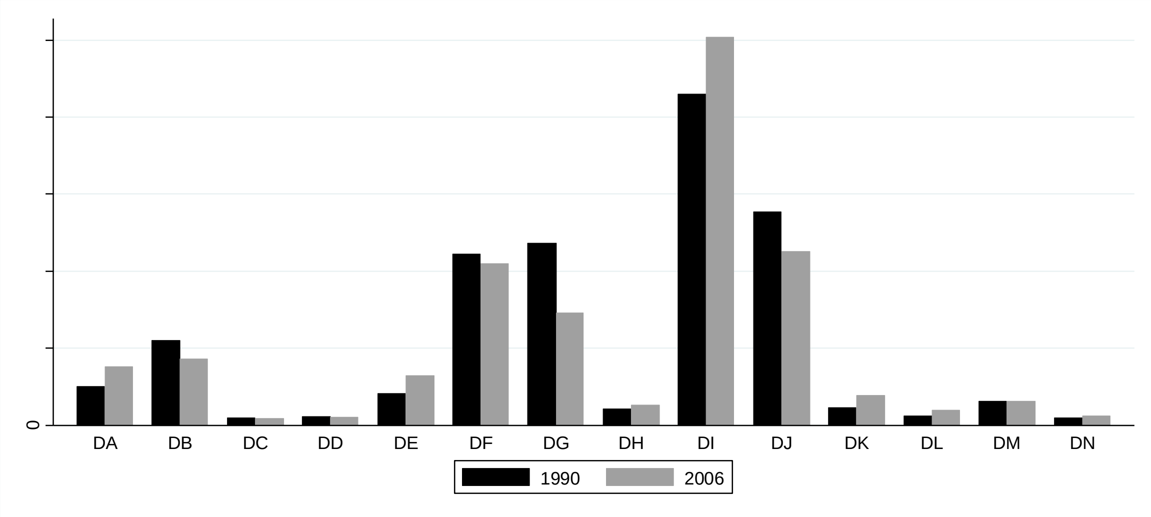

Fig. 9: CO_2 emissions of manufacturing sectors

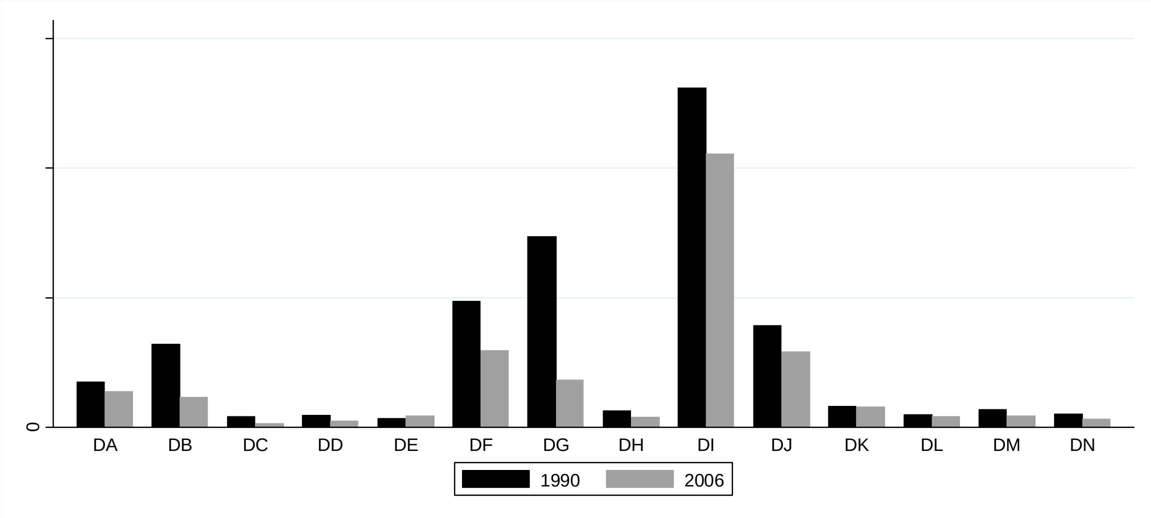

Fig. 10: NOx emissions of manufacturing sectors

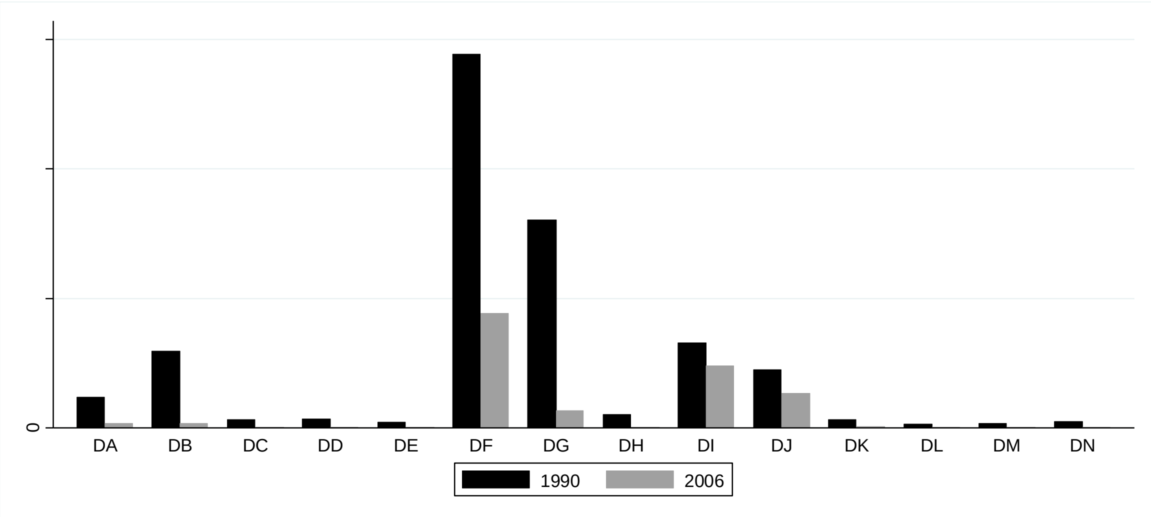

Fig. 11: SOx emissions of manufacturing sectors

Table 1: Nace branches classification

	Nace (Sub-section)	Sector Description
	A	Agriculture
	B	Fishery
	CA	Extraction of energy minerals
	CB	Extraction of non energy minerals
Manufacturing	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	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

Table 2: Correlation matrix

	ln(VA/L)	ln(L)	TO_{EU15}*	$TO_{extraEU15}$*	R&D/VA**
$\ln(CO_2)$	0.091	0.1282	-0.1949	-0.2958	-0.0035
$\ln(NO_x)$	-0.3449	0.2165	-0.3695	-0.5511	0.2092
$\ln(SO_x)$	-0.3571	0.192	-0.4768	-0.5778	0.2369
$\ln(CO_2/L)$	0.4507	-0.5403	-0.0622	-0.1519	-0.0221
$\ln(NO_x/L)$	-0.1464	-0.1343	-0.3145	-0.4958	0.213
$\ln(SO_x/L)$	-0.3011	0.0883	-0.4596	-0.5291	0.2366
ln(VA/L)	-	-0.5754	-0.0496	-0.231	-0.2821
ln(L)	-0.5754	-	-0.2872	-0.3172	0.0408
TO_{EU15}*	-0.0496	-0.2872	-	0.6927	0.3919
$TO_{extraEU15}$*	-0.231	-0.3172	0.6927	-	0.3157
R&D/VA**	-0.2821	0.0408	0.3919	0.3157	-

* Only for branches belonging to D and years 1995-2004
** Only for branches belonging to D and years 1992-2003

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

Table 3: Descriptive statistics (VA/L)

	Aggregate [29 branches; 1990-2006]	Manufacturing [14 branches; 1990-2006]	Services [9 branches; 1990-2006]	Trade [14 branches; 1995-2004]	R&D [14 branches; 1992-2003]
Mean	61.73	52.47	49.12	54.44	54.26
St. deviation	67.08	39.86	22.58	40.16	43.56
Min	11.5	22.94	27.11	26.1	25.15
	(A, 1990)	(DD, 1990)	(H, 2004)	(DD, 1995)	(DD, 1993)
Max	528.5	266.04	112.35	266.04	266.04
	(CA, 2000)	(DF, 1995)	(K, 1990)	(DF, 1995)	(DF, 1995)
I decile	27.11	29.59	31.26	30.83	29.76
II decile	31.7	31.87	32.99	32.99	32.45
III decile	33.82	36.1	34.1	41.11	36.11
IV decile	38.68	41.55	38.36	43.65	41.83
V decile	41.8	43.12	40.21	45.44	44.23
VI decile	45.23	45.69	41.64	46.78	45.88
VII decile	48.38	47.27	47.17	47.93	47.11
VIII decile	64.03	49.21	68.2	49.47	48.85
IX decile	110.37	79.83	87.28	80.17	78.05

Table 4: Descriptive statistics (L)

	Aggregate [29 branches; 1990-2006]	Manufacturing [14 branches; 1990-2006]	Services [9 branches; 1990-2006]	Trade [14 branches; 1995-2004]	R&D [14 branches; 1992-2003]
Mean	783.32	355.58	1585.19	350.56	352.51
St. deviation	793.02	210.76	800.9	209.69	206.25
Min	6	24	588	24	24
	(CA, 2001)	(DF, 2003)	(J, 2000)	(DF, 2003)	(DF, 2003)
Max	3660	894	3660	859	859
	(G, 1991)	(DB, 1990)	(G, 1991)	(DJ, 2003)	(DJ, 2003)
I decile	38	180	612	185	185
II decile	186	203	973	206	206
III decile	243	217	1232	214	217
IV decile	292	260	1397	253	256
V decile	478	276	1450	272	273
VI decile	638	320	1509	316	319
VII decile	1136	454	1573	446	446
VIII decile	1455	529	1666	531	508
IX decile	1622	698	3353	638	698

Notes (Tables 5 to 14): Under coefficients (*10% significance, **5%, ***1%), between square brackets, robust (clustered) standard errors are shown. Below 'Stagnation' coefficients, average emissions in 2002-2006 given 1990-2001 average equal to 100% are shown. *F test* is the joint test of significance of coefficients. We tested for groupwise heteroskedasticity (Baum, 2001): in all estimates we rejected the null hypothesis of homoskedasticity and computed robust clustered standard errors. TP both for *VA/L* and *L* are shown. Underlined TP are outside the range of the observations of *VA/L* or *L*

Table 5: EKC models for CO_2

	EKC 1 [aggr]	**EKC 2 [manuf]**	**EKC 3 [serv]**	**EKC 4a [TO_{EU15}]**	**EKC 4b [$TO_{extraEU15}$]**	**EKC 5 [R&D/VA]**
	ln(CO_2/L)	**ln(CO_2/L)**	**ln(CO_2/L)**	**ln(CO_2/L)**	**ln(CO_2/L)**	**ln(CO_2/L)**
ln(VA/L)	0.5079***	2.8907***	-7.3623***	1.2759**	1.707***	2.5541***
	[0.06]	[0.4]	[1.41]	[0.54]	[0.57]	[0.49]
$ln(VA/L)^2$		-0.2773***	0.9182***	-0.1033*	-0.1546***	-0.2392***
		[0.04]	[0.18]	[0.05]	[0.06]	[0.05]
TO_{EU15}				-0.0438		
				[0.04]		
$TO_{extraEU15}$					-0.0987***	
					[0.03]	
R&D/VA						1.5344*
						[0.79]
Stagnation	0.031**	0.0166	-0.0422*	0.0107	0.024	0.0034
	[0.01]	[0.02]	[0.02]	[0.02]	[0.02]	[0.03]
	103.15%	101.17%	95.86%	101.08%	102.42%	100.34%
Constant	7.3111***	2.8972***	22.5223***	6.5713***	5.7139***	3.5964***
	[0.22]	[0.92]	[2.7]	[1.3]	[1.36]	[1.14]
R^2 (overall)	0.2884	0.5192	0.0676	0.6565	0.562	0.4451
F test	46.54***	23.18***	16.58***	6.45***	9.09***	8.83***
Wald test for groupwise heterosk.	2191.82***	752.66***	749.87***	132.58***	165.97***	409.55***
*N*T*	493	238	153	140	140	168
Period	1990-2006	1990-2006	1990-2006	1995-2004	1995-2004	1992-2003
Turning point(s)	-	183.4896***	55.0896***	480.7862	249.9538***	208.1395***
		[23.61]	[4.21]	[304.89]	[66.51]	[49.62]
Shape (VA/L)		Inverted U shape	U shape	Inverted U shape	Inverted U shape	Inverted U shape

Table 6: STIRPAT models for CO_2

	STIRPAT 1 [aggr]	**STIRPAT 2 [manuf]**	**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)**
ln(VA/L)	0.2093***	2.4495***	-0.5955***	1.2044**	1.7333***	2.2381***
	[0.05]	[0.46]	[0.15]	[0.55]	[0.58]	[0.52]
$ln(VA/L)^2$		-0.2347***		-0.0989*	-0.1633***	-0.2111***
		[0.05]		[0.05]	[0.06]	[0.05]
ln(L)	0.3297***	0.7018***	14.8533***	0.6409***	0.5427***	0.6184***
	[0.07]	[0.13]	[3.25]	[0.2]	[0.2]	[0.18]
$ln(L)^2$			-0.9878***			
			[0.22]			
TO_{EU15}				-0.0642		
				[0.04]		
$TO_{extraEU15}$					-0.1339***	
					[0.03]	
R&D/VA						1.3762*
						[0.82]
Stagnation	0.0415***	0.0121	0.037	0.0081	0.0241	0.0015
	[0.01]	[0.01]	[0.02]	[0.02]	[0.02]	[0.02]
	104.23%	101.22%	103.77%	100.82%	102.44%	100.15%
Constant	12.4765***	5.6346***	-38.1093***	8.8268***	8.35***	6.5434***
	[0.51]	[1.61]	[12.03]	[1.75]	[1.73]	[2.01]
R^2 (overall)	0.0964	0.0195	0.0337	0.0074	0.0113	0.019
F test	12.95***	9.96***	10.3***	7.61***	11.9***	4.33***
Wald test for groupwise heterosk.	2404.99***	858.4***	516.34***	206.19***	290.66***	637.21***
*N*T*	493	238	153	140	140	168
Period	1990-2006	1990-2006	1990-2006	1995-2004	1995-2004	1992-2003
TP (VA/L)	-	184.5503***	-	441.1626	201.5001***	200.2935***
		[27.13]		[282.92]	[51.48]	[52.62]
TP (L)	-	-	1842.021***	-	-	-
			[133.84]			
Shape (VA/L)		Inverted U shape		Inverted U shape	Inverted U shape	Inverted U shape

Table 7: EKC models for NOx

	EKC 1 [aggr]	EKC 3 [manuf]	EKC 3 [serv]	EKC 4a [TO_{EU15}]	EKC 4b [$TO_{extraEU15}$]	EKC 5 [R&D/VA]
	ln(NOx/L)	**ln(NOx/L)**	**ln(NOx/L)**	**ln(NOx/L)**	**ln(NOx/L)**	**ln(NOx/L)**
ln(VA/L)	-0.1322	-3.6714***	-10.5608***	0.0682	-0.0663	-4.336***
	[0.1]	[0.58]	[2.07]	[0.18]	[0.19]	[0.83]
ln(VA/L)^2		0.3673***	1.3038***			0.4276***
		[0.06]	[0.27]			[0.1]
TO_{EU15}				-0.1141		
				[0.1]		
$TO_{extraEU15}$					-0.2306**	
					[0.09]	
R&D/VA						3.9105**
						[1.83]
Stagnation	-0.3038***	-0.2284***	-0.3607***	-0.2054***	-0.1733***	-0.2395***
	[0.02]	[0.03]	[0.04]	[0.02]	[0.02]	[0.04]
	73.8%	79.58%	69.72%	89.21%	84.09%	78.7%
Constant	4.1063***	12.3104***	23.8938***	3.5335***	4.1134***	13.8733***
	[0.37]	[1.37]	[3.93]	[0.75]	[0.77]	[1.76]
R^2 (overall)	0.004	0.2516	0.0101	0.1238	0.0129	0.4135
F test	115.97***	64.07***	43.37***	33.7***	34.37***	24.28***
Wald test for groupwise heterosk.	3465.87***	751.46***	1124.19***	255.8***	357.46	598.58***
*N*T*	493	238	153	140	140	168
Period	1990-2006	1990-2006	1990-2006	1995-2004	1995-2004	1992-2003
Turning point(s)	-	148.1913***	57.4017***	-	-	159.203***
		[27.54]	[5.18]			[58.43]
Shape (VA/L)	Linear	U shape	U shape	Linear	Linear	U shape

Table 8: STIRPAT models for NOx

	STIRPAT 1 [aggr]	STIRPAT 2 [manuf]	STIRPAT 3 [serv]	STIRPAT 4a [TO_{EU15}]	STIRPAT 4b [$TO_{extraEU15}$]	STIRPAT 5 [R&D/VA]
	ln(NOx)	**ln(NOx)**	**ln(NOx)**	**ln(NOx)**	**ln(NOx)**	**ln(NOx)**
ln(VA/L)	-0.4704***	-3.6616***	-1.1662***	0.0351	-0.143	-4.345***
	[0.11]	[0.61]	[0.25]	[0.18]	[0.2]	[0.9]
ln(VA/L)^2		0.3663***				0.4284***
		[0.06]				[0.11]
ln(L)	0.2409*	1.0066***	-1.0036***	0.5959	0.3747	0.9891***
	[0.14]	[0.16]	[0.24]	[0.37]	[0.34]	[0.31]
ln(L)^2						
TO_{EU15}				-0.1377		
				[0.1]		
$TO_{extraEU15}$					-0.2763***	
					[0.09]	
R&D/VA						3.9059**
						[1.89]
Stagnation	-0.2919***	-0.2283***	-0.1474***	-0.2084***	-0.1734***	-0.2396***
	[0.02]	[0.03]	[0.05]	[0.02]	[0.02]	[0.04]
	74.68%	79.59%	86.3%	81.19%	84.08%	78.7%
Constant	9.956***	12.2497***	21.6995***	5.9651**	7.9698***	13.9576***
	[1.1]	[1.85]	[2.39]	[2.48]	[2.34]	[3.08]
R^2 (overall)	0.1568	0.0326	0.2084	0.0054	0.0256	0.0665
F test	88.55***	72.03***	29.6***	27.8***	28.33***	25.16***
Wald test for groupwise heterosk.	2178.24***	752.52***	555.46***	170.98***	227.11***	597.61***
*N*T*	493	238	153	140	140	168
Period	1990-2006	1990-2006	1990-2006	1995-2004	1995-2004	1992-2003
TP (VA/L)	-	148.1219***	-	-	-	159.3695***
		[27.17]				[57.45]
TP (L)	-	-	-	-	-	-
Shape (VA/L)	Linear	U shape	Linear	Linear	Linear	U shape

Table 9: EKC models for SOx

	EKC 1 [aggr]	EKC 2 [manuf]	EKC 3 [serv]	EKC 4a [TO_{EU15}]	EKC 4b [$TO_{extraEU15}$]	EKC 5 [R&D/VA]
	ln(SOx/L)	**ln(SOx/L)**	**ln(SOx/L)**	**ln(SOx/L)**	**ln(SOx/L)**	**ln(SOx/L)**
ln(VA/L)	-6.6233***	-12.8215***	-33.3566***	-12.0515***	-10.0509***	-15.6653***
	[1.43]	[1.43]	[7.79]	[2.91]	[3.47]	[1.84]
$ln(VA/L)^2$	0.6052***	1.253***	4.0584***	1.167***	0.9143**	1.5378***
	[0.16]	[0.15]	[1]	[0.29]	[0.36]	[0.21]
TO_{EU15}				-0.7015***		
				[0.21]		
$TO_{extraEU15}$					-0.7541***	
					[0.29]	
R&D/VA						9.0048***
						[3.33]
Stagnation	-1.1568***	-0.9067***	-1.064***	-0.5431***	-0.4879***	-0.6343***
	[0.07]	[0.07]	[0.12]	[0.07]	[0.07]	[0.08]
	31.45%	40.39%	34.51%	58.1%	61.39%	53.03%
Constant	18.747***	33.7925***	68.282***	32.8402***	28.7501***	40.2313***
	[3.08]	[3.25]	[15.15]	[6.88]	[7.85]	[4.09]
R^2 (overall)	0.0263	0.1386	0.0005	0.1154	0.3175	0.3288
F test	186.42***	140.41***	40.16***	34.45***	31.24***	62.39***
Wald test for groupwise heterosk.	615.95***	84.21***	161.86***	46.55***	52.37***	105.32***
*N*T*	493	238	153	140	140	168
Period	1990-2006	1990-2006	1990-2006	1995-2004	1995-2004	1992-2003
Turning point(s)	237.8917***	167.73***	60.92***	174.7445***	243.851***	162.9707***
	[90.09]	[13.67]	[6.29]	[21.54]	[90.14]	[24.58]
Shape (VA/L)	U shape	U shape	U shape	U shape	U shape	U shape

Table 10: STIRPAT models for SOx

	STIRPAT 1 [aggr]	STIRPAT 2 [manuf]	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)**
ln(VA/L)	-9.8459***	-13.0989***	-3.8979***	-1.1129**	-1.8122***	-16.8727***
	[1.68]	[1.65]	[0.87]	[0.49]	[0.56]	[2.32]
$ln(VA/L)^2$	0.9954***	1.2798***				1.645***
	[0.18]	[0.17]				[0.27]
ln(L)	6.6194***	0.8126	-4.7845***	-12.8234**	-17.2566***	-0.4577
	[1.16]	[0.5]	[0.68]	[5.88]	[6.57]	[0.67]
$ln(L)^2$	-0.5253***			1.1051**	1.4439***	
	[0.1]			[0.49]	[0.54]	
TO_{EU15}				-0.9107***		
				[0.22]		
$TO_{extraEU15}$					-1.1358***	
					[0.23]	
R&D/VA						8.4005*
						[4.28]
Stagnation	-1.0622***	-0.9095***	-0.45***	-0.5974***	-0.506***	-0.6414***
	[0.08]	[0.07]	[0.13]	[0.07]	[0.07]	[0.09]
	34.57%	40.27%	63.76%	55.03%	60.29%	52.66%
Constant	11.4022**	35.5134***	57.3656***	50.5906***	67.1849***	51.4881***
	[4.94]	[5.85]	[7.41]	[18.74]	[20.14]	[7.13]
R^2 (overall)	0.0527	0.086	0.0668	0.243	0.2297	0.1808
F test	120.62***	117.2***	44.9***	25.17***	30.18***	39.13***
Wald test for groupwise heterosk.	647.23***	87.91***	717.53***	115.74***	37.74***	88.31***
*N*T*	493	238	153	140	140	168
Period	1990-2006	1990-2006	1990-2006	1995-2004	1995-2004	1992-2003
TP (VA/L)	140.5643***	166.9534***	-	-	-	168.7405***
	[22.8]	[13.58]				[32.65]
TP (L)	544.5636**	-	-	330.8694*	393.6693***	-
	[212.72]			[174.69]	[134.85]	
Shape (VA/L)	U shape	U shape	Linear	Linear	Linear	U shape

Table 11: SUR unconstrained estimates for CO_2 (dependent variable: $\ln(CO_2/L)$)

Branch	ln(VA/L)	$\ln(VA/L)^2$	Shape (VA/L)	TP	VA/L Min	VA/L Year	VA/L Max	VA/L Year	Stagn.	Stagn. (%)	Constant
DA	2.4189*** [0.23]	-	Linear	-	37.99	1990	47.95	2000	0.1836*** [0.05]	120.15%	0.4785 [0.87]
DB	16.2782*** [1.46]	-2.2945*** [0.21]	Inv. U shape	34.7145*** [0.55]	23.34	1990	34.78	2000	-0.0533 [0.03]	94.81%	-19.1502*** [2.5]
DC	45.1774*** [1.53]	-6.5425*** [0.22]	Inv. U shape	31.5834*** [0.11]	25.11	1991	32.58	2001	0.0189 [0.03]	101.91%	-69.4115*** [2.6]
DD	15.94*** [2.41]	-2.2944*** [0.36]	Inv. U shape	32.2564*** [0.68]	22.94	1990	32.99	2001	-0.0056 [0.03]	99.44%	-18.8895*** [4.04]
DE	-25.5248* [15.32]	3.6168* [2]	U shape	<u>34.0792</u>*** [5.65]	40.95	1990	51.46	2001	0.1121*** [0.03]	111.86%	54.5399* [29.3]
DF	0.1429*** [0.02]	-	Linear	-	96.92	2006	266.04	1995	0.0237 [0.03]	102.40%	12.9344*** [0.09]
DG	22.4233*** [5.2]	-2.6966*** [0.61]	Inv. U shape	63.9241*** [1.46]	57	1990	82.71	2004	-0.1081*** [0.03]	89.75%	-35.1641*** [11.01]
DH	38.0536*** [7.09]	-4.9565*** [0.94]	Inv. U shape	46.4664*** [0.55]	40.12	1990	49.18	2006	0.027 [0.02]	102.74%	-63.5661*** [13.41]
DI	-38.0085*** [2.6]	5.2095*** [0.35]	U shape	38.3977*** [0.32]	37.13	1991	50.17	2006	-0.0098 [0.02]	99.02%	81.1714*** [4.86]
DJ	42.916*** [6.9]	-6.0225*** [0.94]	Inv. U shape	35.2677*** [0.6]	32.65	1990	43.03	2002	-0.1531*** [0.04]	85.80%	-65.9376*** [12.6]
DK	110.5257*** [14]	-14.156*** [1.81]	Inv. U shape	49.5927*** [0.29]	42.19	1993	50.09	2000	-0.0151 [0.05]	98.50%	-206.9535*** [27.11]
DL	30.8633*** [2.75]	-3.8026*** [0.36]	Inv. U shape	<u>57.8702</u>*** [1.42]	37.38	1990	49.21	2001	0.0064 [0.02]	100.64%	-54.1085*** [5.24]
DM	-85.8531*** [7.86]	11.4303*** [1.04]	U shape	42.7552*** [0.19]	38.02	1993	47.11	2000	0.0817** [0.04]	108.51%	170.497*** [14.86]
DN	44.0742*** [8.46]	-6.1415*** [1.22]	Inv. U shape	<u>36.1696</u>*** [0.87]	28.91	1991	36.11	2000	0.07*** [0.02]	107.25%	-70.8135*** [14.68]

Breusch-Pagan test of independence (Chi 2): 186.514***

Table 12: SUR unconstrained estimates for NOx (dependent variable: ln(NOx/L))

Branch	ln(VA/L)	$ln(VA/L)^2$	Shape (VA/L)	TP	VA/L				Stagn.	Stagn. (%)	Constant
					Min	Year	Max	Year			
DA	-71.9495*** 8.31	9.4214*** 1.11	U shape	45.5321*** [0.46]	37.99	1990	47.95	2000	-0.0239 0.06	97.64%	140.8274*** 15.59
DB	-12.68*** 4.61	1.646** 0.68	U shape	47.0722*** [9.53]	23.34	1990	34.78	2000	-0.174*** 0.06	84.03%	27.3669*** 7.76
DC	-0.7174*** 0.11	-	Linear	-	25.11	1991	32.58	2001	-0.4607*** 0.06	63.08%	5.1077*** 0.38
DD	19.4571*** 5.97	-3.0138*** 0.9	Inv. U shape	25.2291*** [0.86]	22.94	1990	32.99	2001	-0.3065*** 0.04	73.6%	-28.208*** 9.92
DE	2.2251*** 0.17	-	Linear	-	40.95	1990	51.46	2001	-0.0559 0.04	94.57%	-5.7349*** 0.66
DF	0.5055*** 0.05	-	Linear	-	96.92	2006	266.04	1995	0.0392 0.09	94.9%	4.7617*** 0.26
DG	146.9745*** 14.04	-17.888*** 1.65	Inv. U shape	60.836*** [0.94]	57	1990	82.71	2004	0.0392 0.09	103.99%	-296.1199*** 29.86
DH	-54.4343*** 16.95	6.8872*** 2.23		52.0312*** [2.54]	40.12	1990	49.18	2006	-0.259*** 0.07	77.19%	110.7577*** 32.35
DI	-15.6434*** 3.64	2.1133*** 0.48	U shape	40.4964*** [0.77]	37.13	1991	50.17	2006	-0.077*** 0.02	92.59%	35.0156*** 6.85
DJ	84.6256*** 11.63	-11.8002*** 1.59	Inv. U shape	36.0808*** [0.41]	32.65	1990	43.03	2002	-0.246*** 0.06	78.19%	-147.7296*** 21.21
DK	113.0203*** 15.3	-14.7174*** 1.99	Inv. U shape	46.5104*** [0.19]	42.19	1993	50.09	2000	-0.3235*** 0.03	72.36%	-214.0393*** 29.36
DL	44.0212*** 3.6	-5.7924*** 0.47	Inv. U shape	44.6966*** [0.16]	37.38	1990	49.21	2001	-0.3169*** 0.03	72.84%	-81.1181*** 6.85
DM	-18.7538*** 5.97	2.2454*** 0.79	U shape	65.1061*** [9.53]	38.02	1993	47.11	2000	-0.0961*** 0.03	90.84%	41.733*** 11.23
DN	30.0846*** 4.98	-4.3949*** 0.71	Inv. U shape	30.6506*** [0.43]	28.91	1991	36.11	2000	-0.3591*** 0.03	69.83%	-48.7168*** 8.7

Breusch-Pagan test of independence (Chi 2): 174.172***

Table 13: SUR unconstrained estimates for SOx (dependent variable: ln(SOx/L))

Branch	ln(VA/L)	$ln(VA/L)^2$	Shape (VA/L)	TP	VA/L Min	VA/L Year	VA/L Max	VA/L Year	Stagn.	Stagn. (%)	Constant
DA	-3.8869*** 0.31	-	Linear	-	37.99	1990	47.95	2000	-0.6775*** 0.13	50.79%	17.8546***
DB	77.3477*** 8.9	-11.9262*** 1.33	Inv. U shape	25.6047*** [0.38]	23.34	1990	34.78	2000	-1.1196*** 0.15	32.64%	-121.3265*** 14.89
DC	-2.6171*** 0.19	-	Linear	-	25.11	1991	32.58	2001	-1.1932*** 0.22	30.32%	11.4836*** 0.66
DD	51.0805*** 9.08	-8.5333*** 1.36	Inv. U shape	19.9455*** [1.12]	22.94	1990	32.99	2001	-0.9951*** 0.14	36.97%	-72.7782*** 15.15
DE	250.5619*** 45.55	-33.5855*** 5.96	Inv. U shape	41.6876*** [0.75]	40.95	1990	51.46	2001	-0.8612*** 0.14	42.27%	-464.7238*** 87.05
DF	0.497*** 0.1	-	Linear	-	96.92	2006	266.04	1995	-0.4734*** 0.1294	62.29%	6.3677*** 0.51
DG	143.7344*** 25.84	-17.477*** 3.05	Inv. U shape	61.0741*** [1.43]	57	1990	82.71	2004	-0.7702*** 0.16	46.29%	-289.108*** 54.62
DH	-7.3134*** 0.6	-	Linear	-	40.12	1990	49.18	2006	-0.9986*** 0.27	36.84%	30.9051*** 2.29
DI	-12.575** 6.04	1.62** 0.8	U shape	49.0387*** [3.69]	37.13	1991	50.17	2006	0.0523 0.03	105.37%	29.7482*** 11.34
DJ	142.7602*** 20.33	-19.9281*** 2.79	Inv. U shape	35.9408*** [0.4]	32.65	1990	43.03	2002	-0.2862*** 0.09	75.11%	-251.5094*** 37.05
DK	201.9892*** 55.51	-26.9484*** 7.25	Inv. U shape	42.4234*** [0.99]	42.19	1993	50.09	2000	-1.2043*** 0.17	29.99%	-376.2193*** 106.25
DL	119.4797*** 22.96	-16.2367*** 3.05	Inv. U shape	39.619*** [0.71]	37.38	1990	49.21	2001	-1.0277*** 0.16	35.78%	-218.1358*** 43.16
DM	77.7656* 43.89	-11.0319* 5.84	Inv. U shape	33.9392*** [4.3]	38.02	1993	47.11	2000	-1.2211*** 0.24	29.49%	-134.8299 82.49
DN	-5.4027*** 0.32	-	Linear	-	28.91	1991	36.11	2000	-1.3299*** 0.22	26.45%	20.7447*** 1.13

Breusch-Pagan test of independence (Chi 2): 540.947***

Table 14: SUR constrained estimates (manufacturing)

	SUR [manuf]	SUR [manuf]	SUR [manuf]
	$ln(CO_2/L)$	**ln(NOx/L)**	**ln(SOx/L)**
ln(VA/L)	2.8517***	-3.4261***	-11.6507***
	[0.03]	[0.17]	[0.41]
$ln(VA/L)^2$	-0.2745***	0.3455***	1.1463***
	[0.003]	[0.02]	[0.04]
Stagnation	0.0189***	-0.2257***	-0.8337***
	[0.001]	[0.02]	[0.05]
	101.91%	79.79%	43.45%
Breusch-Pagan test of independence (Chi^2)	448.746***	376.77***	632.504***
Test of aggregation bias (Chi^2)	16589.74***	19992.81***	3418.68***
*N*T*	238	238	238
Period	1990-2006	1990-2006	1990-2006
Turning point(s)	180.3537***	142.3858***	161.0529***
	[1.94]	[7.83]	[3.52]
Shape (VA/L)	Inverted U shape	U shape	U shape