The Evolution of Environmental and Labour Productivity Dynamics[♣]

Sector Based Evidence from Italy

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Abstract

This paper provides new empirical evidence on delinking in income-environment dynamic relationships for CO_2 and air pollutants at sector level. A panel dataset based on the Italian NAMEA (National Accounting Matrix including Environmental Accounts) over 1990-2007 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 greenhouse gases, 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 shows 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 shows weak correlation with emissions efficiency. SUR estimators (Seemingly Unrelated Regressions) suggest that, as regards 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, SUR, delinking, structural breaks

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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. Full EKC evidence presents bell shaped environment-income dynamic relationship. This is absolute delinking, while relative kind of delinking is observed when the relationship is still increasing, but with a less than unitary elasticity of environmental pressure with respect to income. Since the pioneering works of Grossman and Krueger (1995), Shafik (1994) and Holtz-Eakin and Selden (1995) a large body of theoretical studies have investigated and tested hypotheses within the EKC framework, which is one of the conceptual models we refer to for delinking analyses. Empirical evidence in support of an EKC dynamics, or an absolute delinking between emissions and income growth[1], is limited and not very robust in the case of CO_2. Decoupling between income growth and CO_2 emissions is not (yet) apparent for many important world economies, and where it is observed, it is relative rather than absolute as usually assumed by the EKC hypothesis[2].

The value of this mainly empirical paper is manifold. First, its originality lies in the very rich NAMEA (National Accounting Matrix including Environmental Accounts)[3] sector

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[1] The reasoning surrounding de-coupling can be framed by reference to the EKC model, insofar it describes the state of the dynamic relationship between environmental pressures and economic drivers. This model proposes an inverted U-shaped relationship between per capita income and environmental pressure. The model implies that in the first stage an increase in income leads to an increase in environmental pressure. In the second stage, above a certain level of income, the environmental pressure will decrease as the economy is better able to invest in less polluting technology, consumers reallocate expenses in favour of greener products, there are more awareness raising campaigns, etc. Even policies that are aimed at re-shaping the business as usual trend towards more environmentally efficient and sustainable paths are likely to be implemented with an increasing strictness and effectiveness in terms of economic development. At a later stage, there might be a potential re-coupling, observed for some pollutants, where environmental pressure grows in spite of increasing income. The scale effects of growth again will outweigh improvements in the efficiency of resource use and management.

[2] The EKC hypothesis is shortly that, for many pollutants, inverted U-shaped relationships between per capita income and pollution is documented. Along the evolution of the literature, researches have also addressed the possibility that, after the turning point, economies may re-invert the income-environment relationship. The main empirical findings have been justified by a variety of theoretical models based on increasing returns to scale in the abatement of pollution (Andreoni and Levinson, 2001), on the Solow growth (the so-called 'Green Solow model' by Brock and Taylor, 2004), on an endogenous growth model (Dinda, 2005), etc. However, some authors (e.g. Borghesi and Vercelli, 2009) in a model that links IPAT and EKC frameworks pointed out that an inverted-U shaped relationship between per capita income and pollution might not be enough to meet sustainability targets.

[3] Briefly, the NAMEA approach originated in a series of studies carried out by Statistics Netherlands. The first NAMEA was developed by the Dutch Central Bureau of Statistics (de Boo et al., 1993). In the NAMEA tables environmental pressures (air emissions and virgin material withdrawal) and economic data (value added, final consumption expenditures and full-time equivalent job) are assigned to the economic branches of resident units directly responsible for environmental and economic phenomena.

The first Italian (national) NAMEA, referring to 1990 data, was published by ISTAT in 2001. The current NAMEA covers 1990-2007. It is worth noting that though we are not close to a full NAMEA at EU level given the patchy availability of economic, environmental data by years and countries, EUROSTAT has based economic-environmental dataset for 1990-2007 (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, 2003; Copeland and Taylor, 2004); (c) whether pre-Kyoto and post-Kyoto dynamics show different empirical structures; (d) which is the role of the 2002-2007 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 associated to productivity growth (1990-2001) and productivity stagnation (2002-2007) different dynamics[4]; 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. We focus on Italy since the usefulness of the NAMEA can be mostly appreciated, given the length of the series, which is unique in the EU. Other countries possess good availability of NAMEA, mainly Spain, The Netherlands and Germany, that led to relevant works, but mainly in input-output frameworks and with cross sectional emphasis (de Haan and Keuning, 1996; de Haan, 2001, 2004; Huppes et al., 2006; Roca and Serrano, 2007a,b, Moll et al., 2007). Such a long and constant history of data generation is to our knowledge very peculiar of Italy and allows robust econometric analyses of income-environment dynamics, structural breaks, sector specific features analysis. Due to these differences, our work is difficultly compared to other EU evidence and constitutes a suggestion for further analyses of that kind on NAMEA basis.

Italy is a relevant case study in the EU for economic and environmental reasons. Besides being a big EU country, it is characterized as Germany by an export industrial led economy; the role of industry and services as far as delinking performances can be appreciated well. In addition, the trade issues we will investigate are of a general content even at a higher EU scale. On the environmental side, we may note some facts. Mainly as

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intensified its commitment: a full EU27 NAMEA is expected to be released by 2011 as a silver bullet of EU strategy on data generation and policy support. it may be used to assess ‘sustainable production and consumption’ performances (Watson and Moll, 2008).

[4] 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). Empirical outcomes are quite similar, as expected. We will discuss the different latent motivations related to the effects of those two time related shocks.

far as CO_2 is concerned, the Italian is not as good as those of Germany, France and UK. Being Germany the most comparable country, in terms of emission, emission efficiency and eco innovation adoptions, gaps are striking and does not add a robust contribution to the EU achievement of Kyoto and EU strategy on carbon and emission targets. Looking at EU data over 1990-2007 (http://dataservice.eea.europa.eu), we observe that Italy is among the 7 countries (all southern and Austria and Finland) showing increases in CO_2 with respect to 1990. Italy is +7% while Germany -22%. We recall that in 2007 Italian emissions weights 11% of EU total (as France, Germany is 19%, UK 13%), while Germany, UK and France presented much higher GDP (respectively 58, 24, 16% higher than Italy). only emissions per capita, but not per GDP, are lower in 2007 for Italy with respect to Germany (8 vs 10 tonnes of GHG equivalent). APAT (2005) shows that after a decrease in emission and first absolute decoupling in 1995-1997, then GHG emissions start increasing, following relative delinking trends, with a further deterioration in 2003, occurred during years of economic stagnation. The stuck in energy efficiency improvements can be an underlying reason, strictly associated with the re-increase of coal energy power generation in this century and of the use of fluoride based gases in industrial processes. ISPRA (2010) in its last 1990-2008 inventory report shows that this negative trend associated to a risk of recoupling ended in 2006-2007, two years with stable or even reduced emissions, but with a new growth trend around 2%. It really seems, quite interestingly, that stagnation correlated with GHG increases, while some growth periods may correlate with decreasing GHG trends. This happened mostly in 1995-1997 and 2006-2007. Energy is the issue. 2006-2007 shows a new reduction of energy consumption after 15 years, which pulls back CO_2 emissions and CO_2 intensity, stable over the 2002-2005 stagnation periods.

It is thus important to reflect on Italian mixed and not very well performances both from a national and EU point of view.

The paper is structured as follows. Section 2 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 CO_2 and other air polluting emissions. Section 5 concludes.

2 Economic growth, environmental efficiency and delinking analyses

Our discussion 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 $I=P \bullet A \bullet T$. 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.

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.

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.

(2005) 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. SDA has been applied to a wide range of topics, including demand for energy (e.g. Jacobsen, 2000; Kagawa and Inamura, 2001, 2004) and pollutant emissions (e.g. Casler and Rose, 1998; Wier, 1998, Femia and Marra Campanale, 2010).

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. 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.[5]

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:

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

In equation (1) environmental technical efficiency[6] (emissions/full-time equivalent jobs) of sector s 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), sector dummy variables (β_{0s}) and a temporal structural break called ‘Stagnation’, coded 0 for 1990-2001 and 1 for 2002-2007. Logarithmic form of the dependent and explanatory 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)

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[5] 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.

[6] Intended as emissions on labour (Mazzanti and Zoboli, 2009).

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[7].

Sector effects (β_{0s}) 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 2002-2007 (both at the aggregate level and the macro-sectors level, as in Figures 1-3) 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[8] (CO_2) and indirect[9] (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 2002-2007, 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. This should provide more insights with respect to usual trade openness indexes (Mazzanti and Zoboli, 2009, finding negligible effects and Managi et al., 2009, that find how trade openness increases emissions for non OECD countries but 'abates' for OECD) Because of the high level of correlation between the two openness indexes (0.66) we analyse them separately to overcome potential collinearity problems. We can then refer to (2) and (3):

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[7] 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.

[8] 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.

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

$$\ln(E_{st}/L_{st}) = \beta_{0s} + \beta_1 Stagnation_{0,1} + \beta_2 \ln(VA_{st}/L_{st}) + \\ + \beta_3 [\ln(VA_{st}/L_{st})]^2 + \beta_4 (TO_{EU15})_{st} + \varepsilon_{st} \tag{2}$$

$$\ln(E_{it}/L_{st}) = \beta_{0s} + \beta_1 Stagnation_{0,1} + \beta_2 \ln(VA_{st}/L_{st}) + \\ + \beta_3 [\ln(VA_{st}/L_{st})]^2 + \beta_4 (TO_{EXTRA\_EU15})_{st} + \varepsilon_{st} \tag{3}$$

For a review of the theoretical reasoning behind the link between trade openness and emissions growth, we refer among others to Copeland and Taylor (2004), Millock et al. (2008), Frankel and Rose (2005), Cole (2003, 2004, 2005), Cole and Elliott (2003), Dietzenbacher and Mukhopadhay (2007) 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. For a review of the literature on the diffusion of innovation through international trade (e.g. innovation embedded in intermediate goods) refer to Keller, 2004.

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 have a beneficial or negative effect on environmental efficiency. Enhancements in environmental performances following innovative efforts are not to be taken for granted given the specific features of any techno-organisational innovations, their correlation with (energy) capital stocks, the relevance of complementarities between innovations[10]. Generally, the adoption of process/product innovations occurs with a delay as a

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[10] As stated by Cohen and Levinthal (1989), the role of R&D for technological change is twofold. On the one hand, R&D aims to discover new processes, products or routines. On the other hand, R&D is necessary to adopt innovations introduced by other agents. This general consideration applies also in the context of eco-innovation and of environmental technological change.

consequence of R&D investments. We use a contemporary R&D/VA ratio because if we use lags we lose too many observations[11]. If we add R&D, equation (4) becomes the estimate basis.

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

Finally, we test the base model (see equation (2)) on manufacturing[12] using SUR[13] (Seemingly Unrelated Regressions) instead of Fixed Effect. SUR estimator has several interesting properties. First, constrained[14] SUR estimates are more efficient than fixed effects (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[15]. 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[16].

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 (Dietz and Rosa, 1994; York et al., 2003) to a single-country sector disaggregation. 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 environmental pressures (Martinez-Zarzoso et al. 2007, Cole and Neumayer 2003). This model allows us to investigate explicitly the role of demographic

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[11] 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-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.

[12] We used SUR estimator only for manufacturing (14 branches for 18 years) because SUR estimator is feasible only when the number of equations (here, number of branches) is lower or equal to the number observations (here, years).

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

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

[15] 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 variance-covariance matrix of errors is an unitary matrix (Baum, 2001).

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

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, 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).

$$E = L * (VA/L) * (E/VA) \tag{5}$$

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

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

$$\ln(E_{st}) = \delta_{0s} + \delta_1 \ln(L_{st}) + \delta_2 \ln(\mathrm{VA}_{st}/\mathrm{L}_{st}) + \varepsilon_{st}{}^{17} \tag{8}$$

$$\begin{aligned} \ln(E_{st}) &= \beta_{0s} + \beta_1 Stagnation_{0,1} + \beta_2 \ln(VA_{st}/L_{st}) + \\ &+ \beta_3 [\ln(VA_{st}/L_{st})]^2 + \beta_4 \ln(L_{st}) + \beta_5 [\ln(L_{st})]^2 + \varepsilon_{st} \end{aligned} \tag{9}$$

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[18]. 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 similarly 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 given 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 (elasticity <1) to employment (or even decrease), 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.

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

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

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

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[19] included in NAMEA for Italy, using panel data disaggregated at sector level.

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)[20]. 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 1990-2007, with a 2-digit Nace (Rev. 1.1) disaggregation level. In the NAMEA tables, environmental pressures (for Italian NAMEA air emissions and virgin material withdrawal) and economic data (output, value added[21], 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[22]. We use only data on economic branches, excluding household consumption expenditure and 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)[23]. We construct trade openness indicators dividing the sum of imports and exports of every CPAteco category by the value added[24] of the corresponding Nace branch:

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[19] 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.

[20] 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.

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

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

[23] 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 1995-2005 (Istat). 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

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

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

where X is export, M is import,[25] *VA_curr* is value added at current prices, *s* is the branch (Nace) or the product (CPAteco) and *t* is the year between 1995 and 2005, the period of reference for the estimates using these covariates.

We also merge NAMEA tables with ANBERD[26] OECD Database containing R&D expenditure of enterprises for 19 OECD countries, covering the period 1987-2004 (for Italy only 1991-2004, thus the period of reference in below regressions). 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.

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. Figures 1-5 depict the observed dynamics of the Italian context on which we focus.

4.1 Carbon dioxide

4.1.1 EKC specifications

The evidence for CO_2 (Table 5) signals a relative delinking in the cases of the aggregate economy and manufacturing[27], with an elasticity of emissions efficiency with regard to labour productivity around 0.42 for the aggregate estimate. This outcome is as expected given that Italy is still lagging behind the Kyoto target[28]. We drop the quadratic term since it is not significant, coherently with a 'general to particular' specification approach deriving from the econometric of time series. The general model incorporates variables from the conceptual model and from past applied works. It should also be well specified, satisfying

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than three units. Data related to such branches are also excluded from the 4-digit disaggregation of COEWEB or in the less detailed disaggregations.

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

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

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

[27] 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 0.34 (relative delinking).

[28] Italy is (among EU_{15}) third for total GHGs, 12th for GHGs per capita and 10th 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.

the assumptions placed on the statistical model. From there, a search would begin for the simplest model that still satisfied the statistical assumptions (Hendry, 1995). A specification with a non significant quadratic term would be over identified.

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. Digging out evidence, we note that the recoupling vanishes, becoming an (expected) absolute delinking (negative linear relationship with elasticity -0.61) when we omit sector K (real estate, renting and business activities)[29], a sort of 'outlier' in this[30] and other cases which we comment on below.

The 'Stagnation' structural break presents an aggregate positive sign of the coefficient while the coefficient for services is negative. However, the economic significance of the estimated coefficients is negligible. Note that the positive sign for the aggregate figure is not driven by manufacturing sectors but might be the result of a move back towards coal in the production of electricity (sector E, which is not included in manufacturing) occurred in recent years as a consequence of high oil prices. Over the same years the Kyoto policy process evolved. We tried (not shown) other structural breaks with reference to Kyoto convention and ratification, with similar results.

It seems, therefore, that neither the Kyoto policy framework nor the 2002 Italian ratification has had significant effects on emissions performance. Manufacturing, which accounts for 38.52% of total direct emissions in 2007, 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[31]. 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[32].

Trade openness (whose data coverage is 1995-2005) is negatively related to emissions for both extra-EU_{15} and EU_{15} covariates, though the size is quite negligible for extra-EU_{15} and statistically significant (at 5%) only for EU_{15} trade dynamics. The pollution haven effect, which is supposed to be generally driven by trade openness, is not supported here. The energy intensive, and capital abundance, an endowment of the Italian industry, can explain such result which is not unexpected (Mazzanti and Zoboli, 2009). In addition, if FDI flows are driven also by stronger environmental policy stringency in the investor's country relative to host country, and in association more polluting industries tend to invest more abroad (Spatareanu, 2007), the relative more lax stringency of Italy with respect to Nordic EU countries is another reason behind negligible pollution haven evidence.

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[29] 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.

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

[31] As an example, the Italian carbon tax proposal of 1999 was never implemented (Martini, 2010).

[32] 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 payment) 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.

On the other hand, the interpretation of the 'positive effect' of European trade on Italian environmental performances may include a number of very interesting 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 (Millock 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.

Thus, trade related innovation/R&D and embodied international knowledge are the possible and very interesting facts, for national economic-environment competitiveness, behind this evidence. It confirms the importance of a common trade area for economic growth and also for environmental performances. The evidence indirectly links to the literature that has analysed direct and indirect trade related innovation effects (Keller, 2004; van Pottelsberghe de la Potterie, 1997; Lumenga Neso et al., 2005; Eaton and Kortum, 1999), which builds up on R&D rent spillovers (Griliches, 1992) and embodied and disembodied technological diffusion (Jaffe, 1986). Trade enables the flowing of innovation between trading partners, or indirect trading partners, with assumed and proved decreasing effects as trade rounds increase. Though decay is observed by distance, external R&D transmitted through trade may matter even more than internal innovation efforts for sector economic and environmental productivity (Franco et al., 2009; Costantini et al., 2010). The evidence that trade increases the quality and number of intermediate inputs is coherent with the 'case study' on the Italian economy. Direct trade effects here could primarily matter: the largest pie of Italian export and import is with Germany, a leader in green technology adoption and diffusion (13% the share of export and 17% that of import, featuring machinery and transport equipment, foodstuffs, ferrous and nonferrous metals, wool, cotton, energy products as primary goods). Trade with Germany (and France the second largest partner) can be environmentally beneficial, 'importing' technology and even stronger implementation and stringency of environmental policies. Cainelli et al. (2010b) survey based data on a major Italian region show that green innovations and green R&D are higher in export oriented and foreign owned firms. R&D knowledge flows can be transmitted through trade, then being observed as tangible innovation facts in the host country, especially when more formal / strict relationships and stronger firm integration between partners, such as merges, formal cooperation, and foreign ownerships are factors added to market trade flows.

Further micro and sector based research is needed along such interesting lines. 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'. These interpretations of the effect of EU trade will apply, with stronger effects, also for pollutants.

R&D overall is not economically but statistically 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, such as the use and aggregation of CIS various waves dealing with eco innovation strategies (only the 2006-2008 wave specifically elicit environmental innovation).

A note on R&D, a proxy of absorptive capacity, is needed. We generally find in this paper a weak or positive statistical significance, and a weak economic significance. One interpretation is that general R&D efforts, even when lagged with respect to environmental efficiency, are still not a driver. R&D could be, and even more in its non lagged form, a real proxy of innovative capacity of a sector rather than a deep internal effort towards the achievement of a comprehensive and environment specific productivity enhancement. Environmental efficiency should require deep specific investments and not occasional monitoring of the external technological environment[33]. An external environment which was and is quite polarised if not poor, in terms of industry environmental strategies (Cainelli et al., 2010a,b). Even in wealthy export oriented areas of Italy, environmental innovations are adopted by 10-20% of manufacturing firms, compared to for example 30-50% of Germany, with strong heterogeneity across sectors. Environmental innovation started to be pursued, and quite recently, by large and internationally linked (through export or ownership relationships) corporations of leading sectors such as ceramics, machinery, metal-products. In a first attempt of merging NAMEA and firm based (AIDA) data Cainelli et al. (2010c) find that though structural higher emission intensity allows higher degrees of freedom for firms and correlates to higher turnovers growth (over 2000-2004), insofar it may probably relax the constraints on growth, on the other hand firms included in sectors that spend more on the environment are not penalised in terms of growth. Another paper that specifically exploit regional NAMEA data (Costantini et al., 2010) for Italy also shows that internal efforts (R&D, patents) is not a major driver of emission efficiency, if compared to sector/regional technological spillovers. This is another direction of fruitful research as soon as more years of regional NAMEA are available.

More specific R&D efforts leading to process / product eco innovations can change the dynamics of the income-environment relationship and also positively affect competiveness. The clear evidence that, in Italy, stagnation (in GDP, and likely in investments) is correlated to lower energy and carbon efficiency is related to this kind of reasoning on innovation-environment-income dynamics interlinks.

Finally, we focus on the higher level of sector heterogeneity provided by SUR models. First, constrained SUR estimates (Table 14) for manufacturing confirm the result of FE estimates. It is worth noting that SUR estimates are more efficient than FE, with lower standard error and the 'Stagnation' structural break that becomes statistically significant (even though the size is negligible).

Unconstrained SUR estimates (Table 11) highlight a high degree of heterogeneity of the income–environment 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 (in the high percentile regarding emission on value added over the 90's, thus this is good news). All other sectors show either linear (as DF, Coke, refined petroleum products, and nuclear fuel, a highly critical sector for GHG related environmental effects, with regional hot spots (Costantini et al, 2010)) or U shaped[34]. The EKC evidence we find

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[33] We are grateful to one referee for such hint.

[34] 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

in the pooled FE and constrained SUR 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 (+25.62%), for DE, DI and DM, with a U-shape relationship which denotes a worsening in the performance. The evidence is especially striking for ceramics (DI), a leading polluting, export oriented and value added generator, which usually presents high level of eco innovations and green R&D. They seem not sufficient to revert and abate emissions. We 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[35].

4.1.2 STIRPAT specifications

In this type of analysis we refer to effects on emissions *per se*, not emissions technical efficiency, as stated[36]. 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 the first focuses on emissions efficiency and the second on emission levels.

First, we can see that aggregate 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 considered period. We focus on the specific figures for manufacturing and services which we believe are more relevant than aggregate estimates. For manufacturing, the elasticity is positive (0.76). 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 second-last deciles).

On the basis of the empirical evidence, in the considered period 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

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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.

[35] 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). Results show that the Italian paper industry has adopted a wait and see strategy, characterized by conservative and cautious decision making and use of time-flexibility solutions. These are having modest outcomes in terms of innovation. Carbon dioxide emitted by energy-intensive industries cannot be reduced through the use of low-cost end-of-pipe abatement solutions; they require improvements in energy-efficiency and investment in renewable energy.

[36] Future analyses should be directed to use different indicators (such as emissions per value added, more suitable to identify trade-offs/complementarities that emissions per worker) in order to identify possible differences in the results.

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 for SOx) with tendency to recoupling (U shape for manufacturing and services) which are worthy of careful investigation (Tables 7 and 9).

For both NOx and SOx the feature of sector DF explains the final increasing part of the U shape curves[37]. During the period 1990-2000, both emissions and labour productivity increase while the trend reverts in the period 2001-2007 (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 2001-2007, a period when aggregate labour productivity increased by 0.08% (0.01% per year), 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[38]. 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 after 2004 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[39].We 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.

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[37] 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.

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

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

Trade openness shows negative and significant[40] coefficients that are larger for SOx. On the one hand, the extra-EU_{15} related evidence suggests a stronger weight of the 'pollution haven' factor relative to endowments which was absent for CO_2. The local negative externality generated by pollutants may generate more incentives to delocalize pollution intensive productions relative to GHG (which do not give rise to local externalities) intensive ones. On the side of EU_{15} trade, the same motivations outlined for CO2 about the 'race to the top' apply for SOx and NOx.

R&D expenditure is again not (economically) significantly related to (abatement in) emissions, highlighting no complementarities between profit-driven innovation and environmental efficiency. Regarding NOx, the evidence is of a statistically but not economically significant coefficient. As for CO_2, the relation is again positive. The lack of relevance of R&D for pollution efficiency (NOx and SOx) 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.

Unconstrained SUR estimates for SOx (Table 13) allow to highlight the high degree of (significant) heterogeneity across sectors. We observe mixed evidence: strong absolute delinking for some sectors (DA, DC, DD, DH, DM and DN) and only relative delinking for DF. 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 than it was for CO_2, with only a positive sign (DI) and *ceteris paribus* reduction ranging from -74.68% (DN) to -21.28% (DJ). The two most critical sectors, DF and DG, present strong decreases in emission (DF still remaining the worst in levels). Structural breaks are significant. Shapes are inverted U for both sectors, with the turning point for DF outside of the range of observed values (recall the decreasing productivity in the final part).

As regards NOx (Table 12), the picture is also very mixed. Seven cases of bell shaped, five U shapes and even no delinking at all for DF. 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 FE 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, DF (an highlighted outlier) presents a linear relation, driven by lowering productivity, while DI (the worst emitter among all), for which VA/L increases, shows a U shape deriving from an unstable temporal dynamics of emissions.

4.2.2 STIRPAT specifications

As far as the evidence (Tables 8 and 10) of emissions-labour productivity is concerned, the results roughly confirm the EKC analyses. For both SOx and NOx in the aggregate and manufacturing, the same comments on DF as outlier apply as above.

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,

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

negative for services, positive in the aggregate) suggests an emissions saving dynamics. Over time, the size of the emissions/labour ratio reduces.

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 delinking trends for CO_2 and air pollutants at sector level. A panel dataset based on the Italian NAMEA for 1990-2007 was analysed, focusing on emissions efficiency (EKC model) and total emissions (IPAT model). It is worth noting that the IPAT model allows an investigation of the emissions-labour elasticity. Policy related considerations are driven by NAMEA based analyses. On the one hand, this sector based evidence is extremely relevant for adapting and tailoring the EU ETS post Kyoto policies taking into account of sector specificities. Both policy effectiveness – reaching the EU targets, among others Kyoto related and EU 20-20-20 strategic objectives - and its efficiency – distributing burdens to sector depending on cost of abatement and their past contributions to abatement. Policy maker might observe the relative contribution to abatement of industry and services, and then more in detail SUR analyses can disentangle single branches. Bringing together the information on (i) the relative role played in the past by sectors in abating, (ii) their share in emissions generation, (iii) the level of marginal cost of abatement, one can shape a policy according to both 'political', structural economic and economic efficiency rationales. This comprehensive vision might resolve some of the resistances policy makers face when using either just economic-political or efficiency rationales into account on a separate basis. On the other hand, NAMEA based analyses allow and will more and more allow ex post evaluations of structural changes driven by polices, innovation and structural factors, including energy shocks. Decoupling based objectives are more and more emphasised by the EU as goal based pragmatic indicators that have more and more substitute measures linked to the greening of GDP as indicators of sustainability. Delinking analyses are thus at the core of the achievement of EU Lisbon agenda.

Though the period of reference is a business-as-usual, no-policy time setting for GHGs in Italy – but this is on the other hand an interesting scenario to be analysed - we investigate whether the Kyoto policy process caused significant breaks in emission-income dynamics over the period (Kyoto convention, national ratification). The Kyoto process was strictly entangled with a peculiar phase of the Italian economy. We thus also test whether a structural break in the 1990-2007 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. Though the Italian industry is historically one of the most efficient in the EU, we note that its energy efficiency has stabilised since mid 90s. the Italian economic system stalled and even witnessed and increase in the intensity of CO_2 emissions of 0.3% on average since 1990 in the industrial sector, with a worsening performance from 1992 to 2003, that only Spain matches in the EU. Weakest links in industry are mechanic, textile and food bad performances counterbalance chemical and steel good ones. This partly explains the non compliance with Kyoto and some no decoupling or recoupling we observe – even using NAMEA data - for industry as well, in GHG emissions It is true that the most relevant gains in terms of emission reductions can be achieved by targeting more inefficient and almost policy free sectors such as transport and construction/building renewals; nevertheless we show again that industry is still lagging behind the achievement of full recoupling, and it also might have worsened its performances over the past years. The fact that recent works show that more emission intensity manufacturing sectors have grown more in this decade is complementary evidence that may tell you that more policy effort and environmental innovation investments are needed to reshape and make greener the growth of the Italian economy.

SOx and NOx instead present expected decreasing patterns, though it is worth noting that 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.

The strong expansion in trade openness, a crucial driver for an export oriented country such as Italy, presents a negative correlation with emission efficiency, that validates the pollution haven hypothesis when focusing on extra-EU_{15} trade. Nevertheless, it also shows negative signs when only EU_{15} trade is considered: this may be due to technology spillovers, trade related R&D flows, generating a sort of 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). This shows the importance of intra EU trade, still predominant, and of the possibility of enhancing EU competitive advantage not only through EU and national policies but also by trade driven competition, trade relationship, outsourcing, trade in intermediate goods and R&D cooperation. Trade makes EU markets greener and more competitive playing complement role with respect to policies. National policies implemented with higher stringency by some countries (i.e. Germany) can spillover through technological and trade relationships. Finally, general R&D expenditure show weak correlation to emissions efficiency. This may be a sign of 'usual' content of R&D efforts, slightly biased towards environmental aims, and capturing more a propensity of monitoring the external technological environment. Even in wealthy export oriented areas of Italy, environmental innovations are adopted by 10-20% of manufacturing firms, compared to for example 30-50% of Germany, with strong heterogeneity. This is a lever of competitive advantage that has not been exploited so far. Interestingly, it seems instead that 30-50% of export oriented and above all foreign owned firms, coherently with our results, adopt eco innovations. It leaves room for further research towards the aggregation of eco innovation micro data and sector data.

EKC and IPAT derived models provide similar conclusions overall; as far as IPAT is concerned, the emissions-labour elasticity estimated in the latter is generally different from one, 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 assessing the extent to which non-linear shapes emerge from 'average' trends. 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. We highlight as a food for policy makers that among high polluting sectors, 'Basic metals and fabricated metal products' and 'Chemicals, chemical products, and man-made fibres' show promising absolute delinking dynamics, while 'Non-metallic mineral products' and 'Coke, refined petroleum products, and nuclear fuel' show still clear signs of positive correlation between environmental and income trends. Even Food and beverages, a leading Italian sector, does not present good evidence. Recent data has shown very negligible adoption of eco innovation for food firms. For ceramics, the quite high innovative efforts seem insufficient to cope with the very critical emission loads the sector still produces. The sectors that seem to have achieved full delinking around 2000 are minor: Electrical and optical equipment, other manufacturing, and textile. Heterogeneity behind the scene confirms that the overall picture is driven by quite different empirical facts and sector idiosyncrasies. The relevance for management and policy is clear. Above all, industry performances seem to be not on tack with EU climate change and emission targets, and could have worsened during the last years. Given that sectors such as ceramics, paper, food and fuel manufacturing present the worse dynamics, policies might target such economic branches balancing efficiency (marginal costs of abatement), eventual innovation support and political economy considerations (burden sharing), possibly achieving large gains by focusing on hot spots critical establishments or cluster of (district) firms.

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. All those research efforts can enrich NAMEA and its usefulness as a data source, which is currently one of the EU pillar, as the target of setting up a full EU NAMEA by 2011 recognises.

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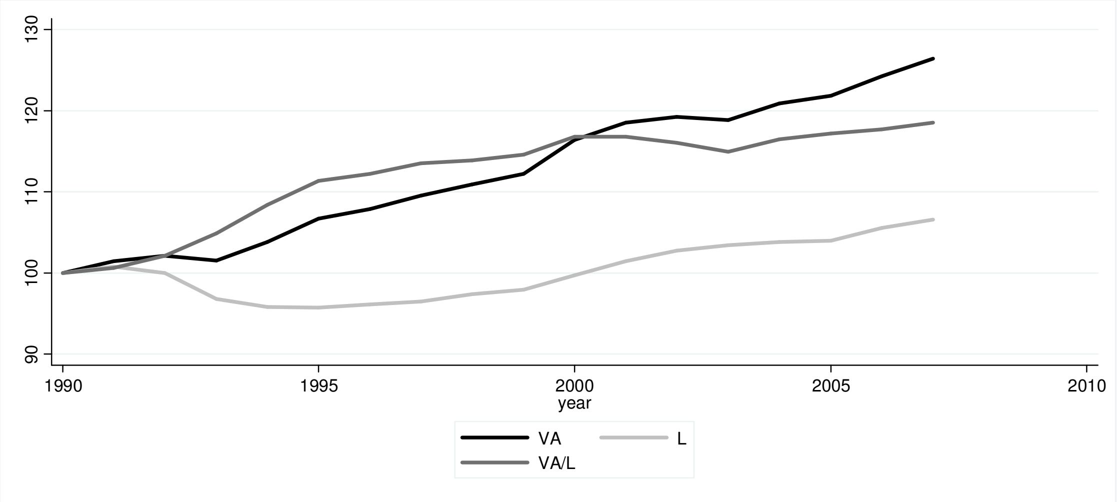

Figure 1: VA, VA/L and L aggregate (1990=100)

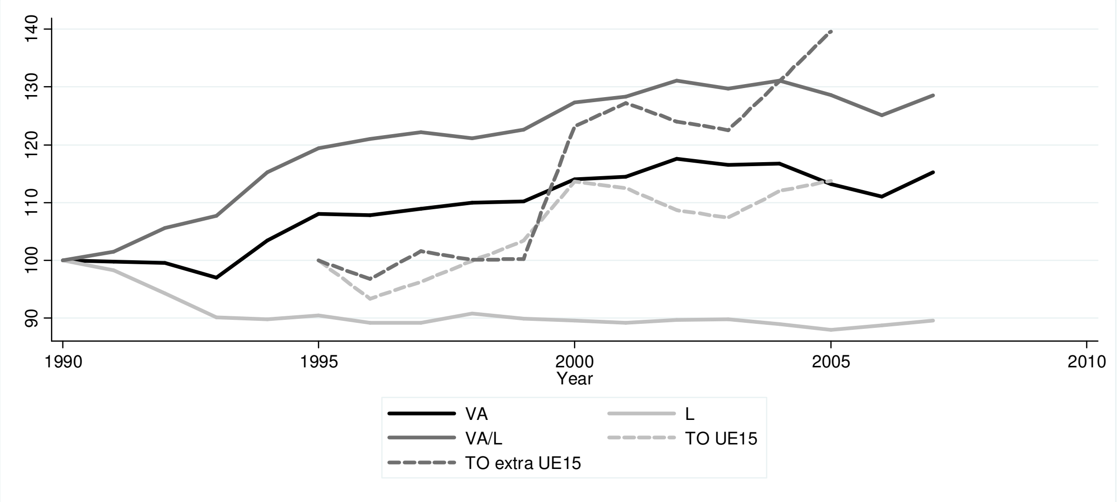

Figure 2: VA, VA/L, L and TO manufacturing (1990=100 for VA, VA/L and L and 1995=100 for TO)

Figure 3: VA, VA/L and L services (1990=100)

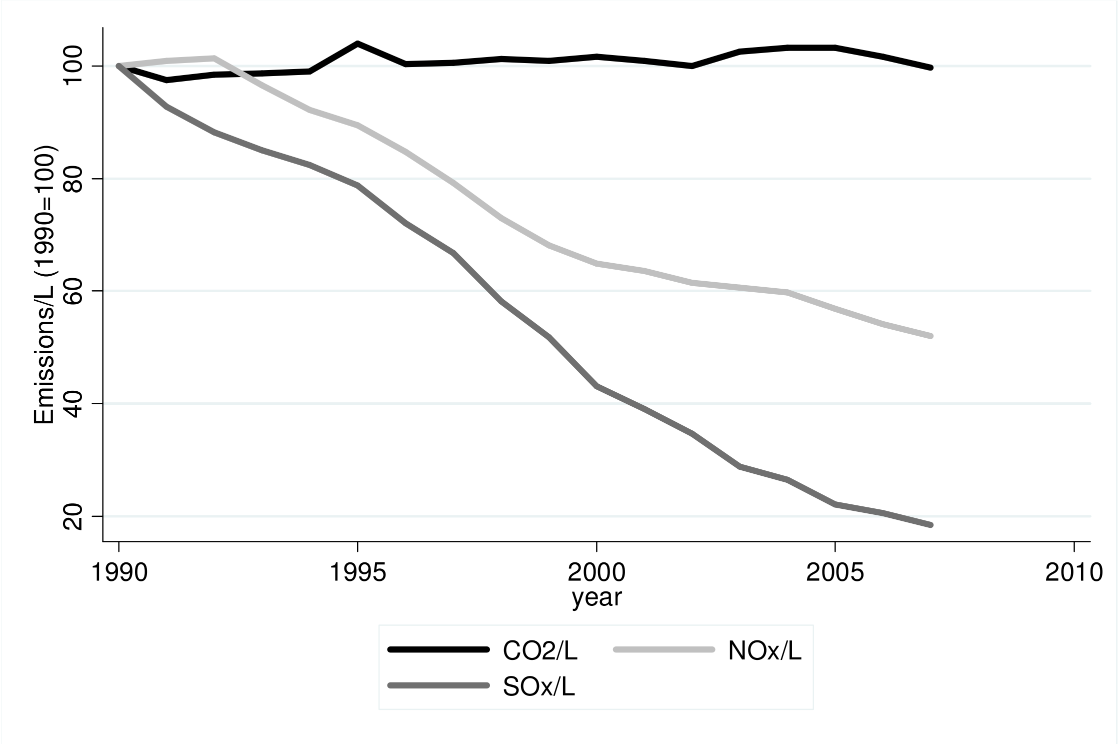

Figure 4: Emission/L trends (aggregate; 1990=100)

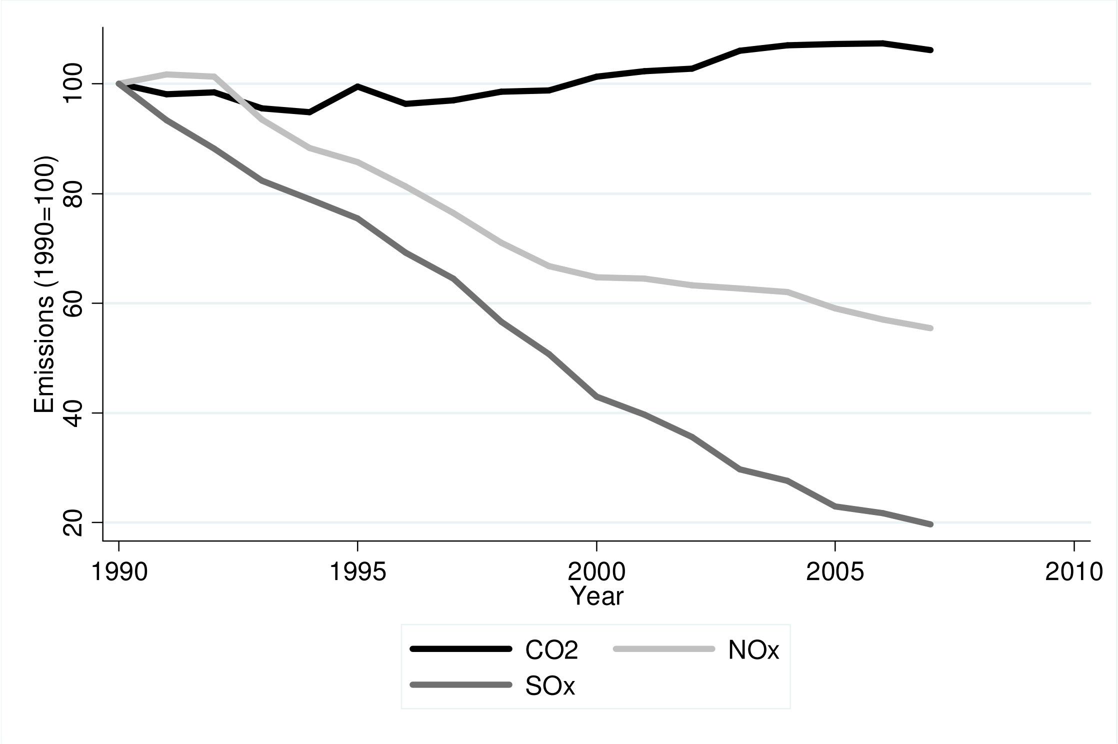

Figure 5: Emission trends (aggregate; 1990=100)

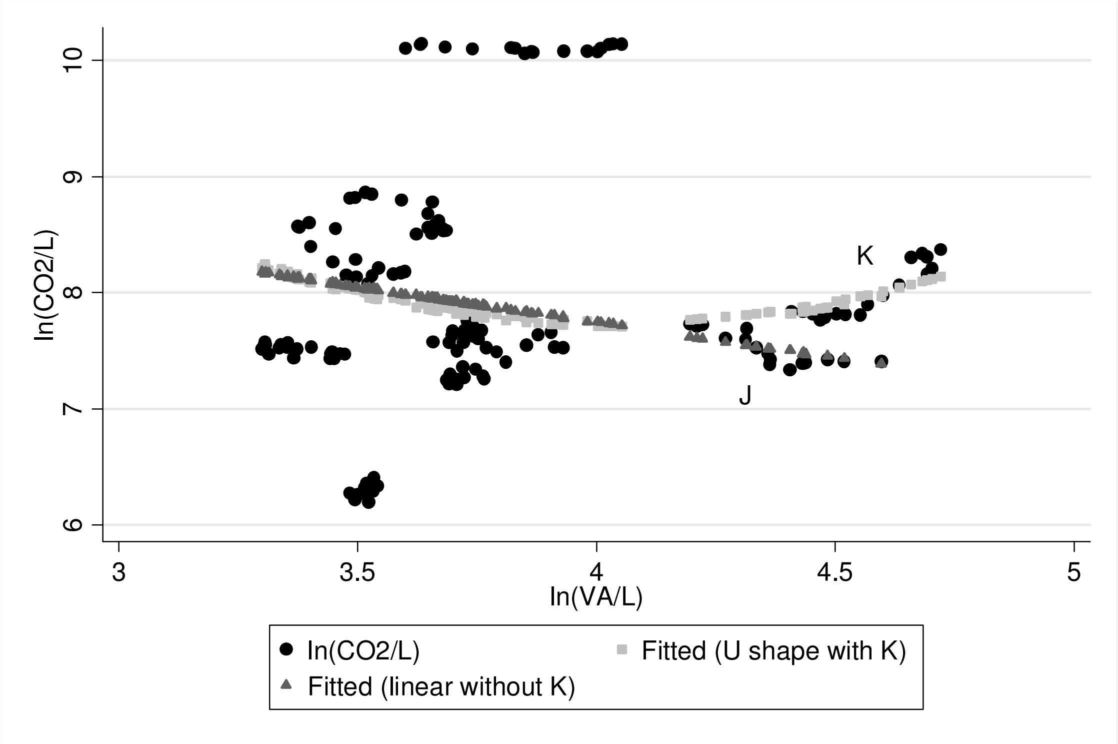

Figure 6: Outlier K in EKC estimates for CO2 (services macro-sector)

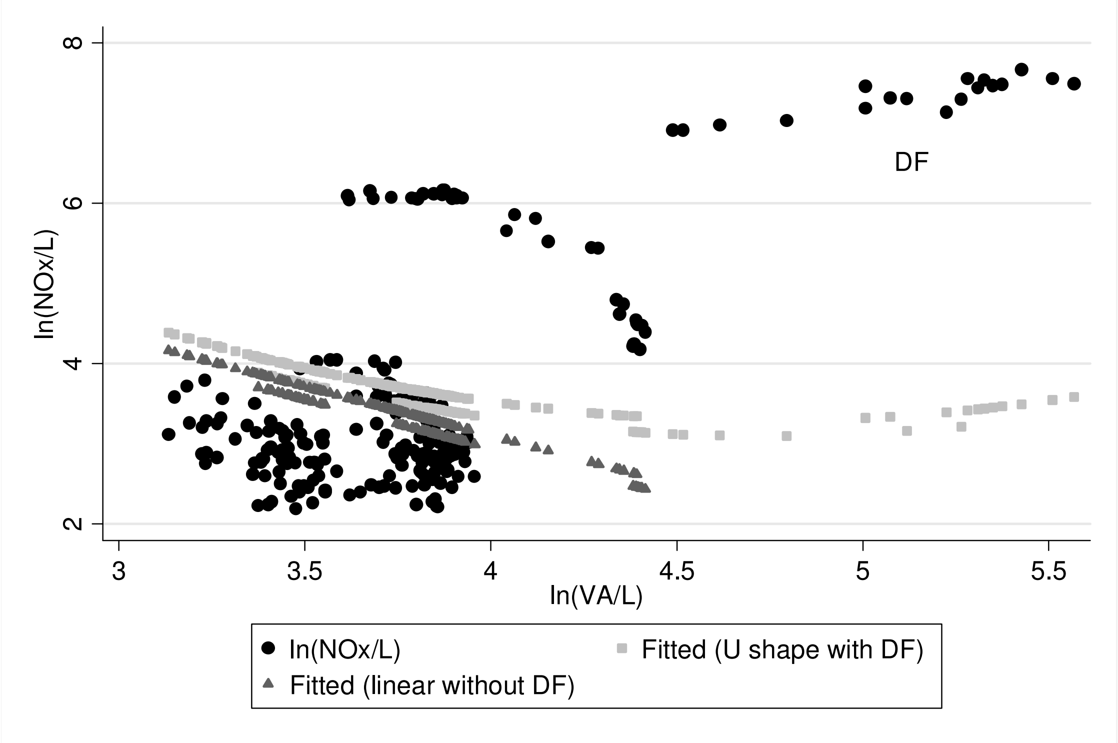

Figure 7: Outlier DF in EKC estimates for NOx (manufacturing)

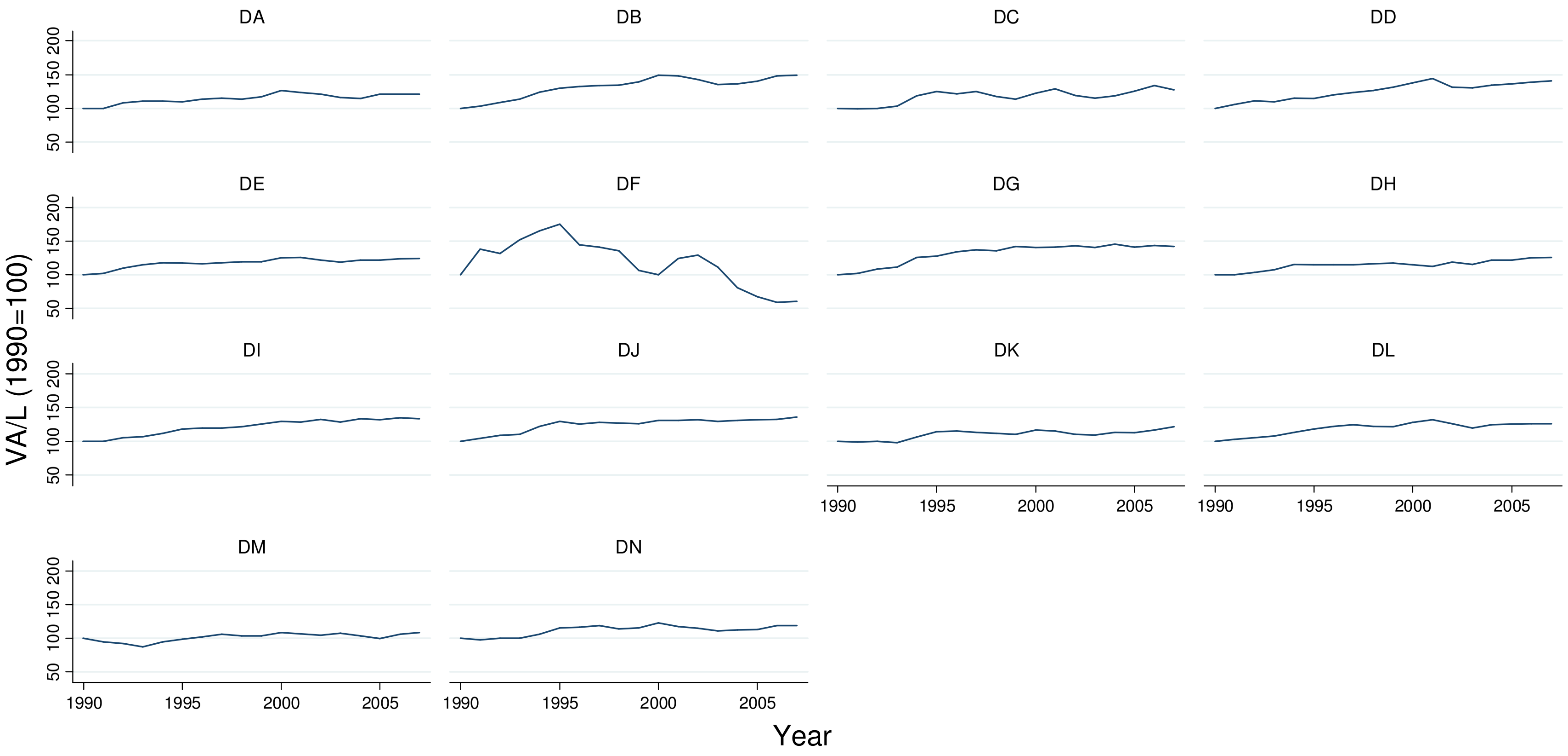

Figure 8: VA/L (normalized 1990=1) trends (manufacturing)

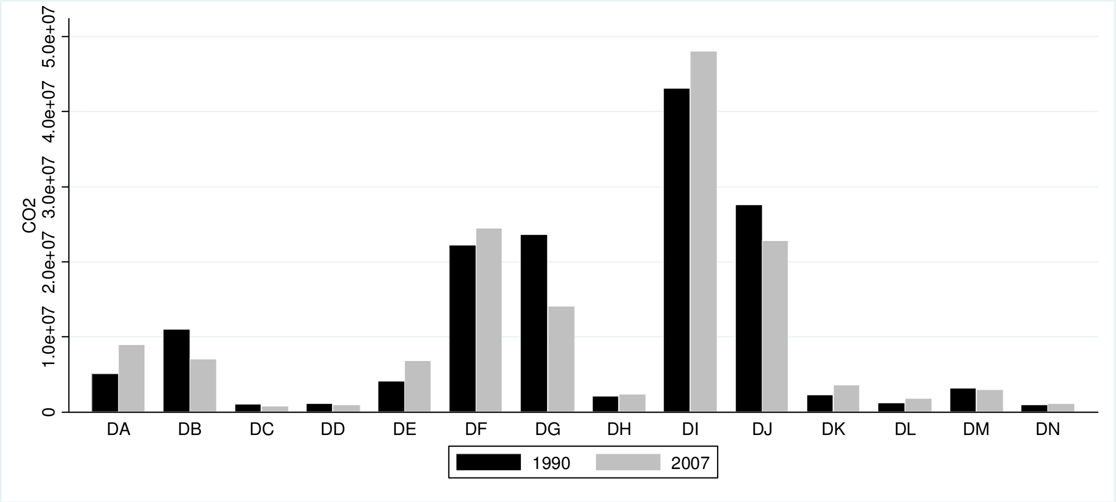

Figure 9: CO_2 emissions of manufacturing sectors

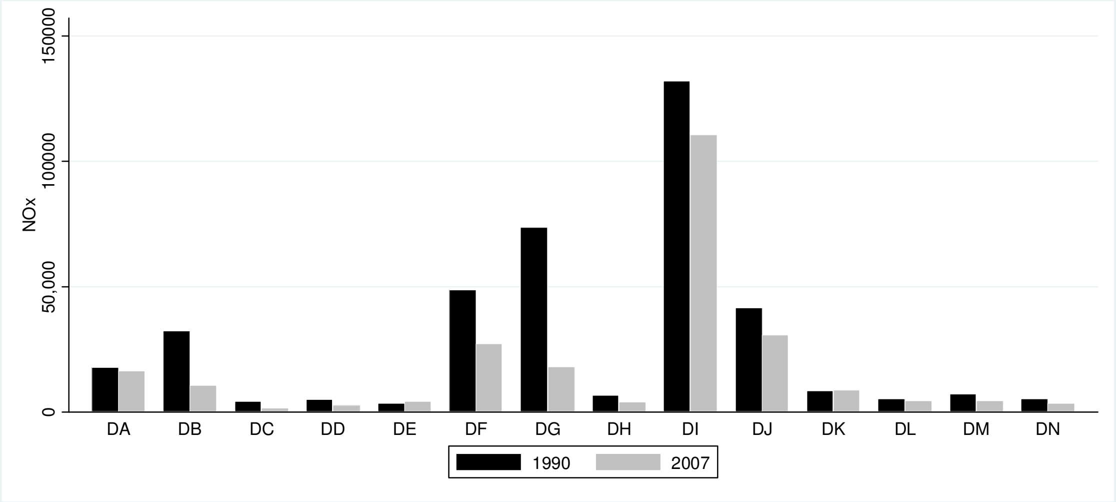

Figure 10: NOx emissions of manufacturing sectors

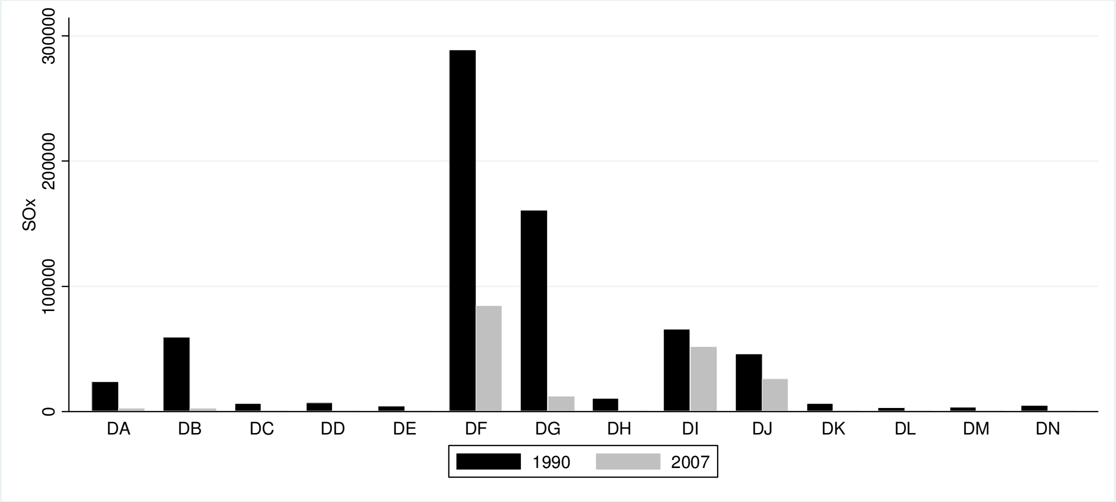

Figure 11: SOx emissions of manufacturing sectors

Table 1: NACE branches classification (Rev. 1.1)

	NACE (Sub-section)	Sector Description
	A	Agriculture, hunting and forestry
	B	Fishing
	CA	Mining and quarrying of energy producing materials
	CB	Mining and quarrying, except of energy producing materials
Manufacturing	DA	Food products, beverages and tobacco
	DB	Textiles and textile products
	DC	Leather and leather products
	DD	Wood and wood products
	DE	Pulp, paper and paper products; publishing and printing
	DF	Coke, refined petroleum products and nuclear fuel
	DG	Chemicals, chemical products and man-made fibres
	DH	Rubber and plastic products
	DI	Other non-metallic mineral products
	DJ	Basic metals and fabricated metal products
	DK	Machinery and equipment n.e.c.
	DL	Electrical and optical equipment
	DM	Transport equipment
	DN	Other manufacturing industries
	E	Electricity, gas and water supply
	F	Construction
Services	G	Wholesale and retail trade
	H	Hotels and restaurants
	I	Transport, storage and communication
	J	Financial intermediation
	K	Real estate, renting and business activities
	L	Public administration and defence; compulsory social security
	M	Education
	N	Health and social work
	O	Other community, social and personal service activities

Table 2: Correlation matrix

	ln(VA/L)	ln(L)	TO_{EU15}*	$TO_{extraEU15}$*	ln(R&D/VA)**
ln(CO_2)	0.02	0.19	-0.20	-0.22	0.26
ln(NO_x)	-0.35	0.28	-0.41	-0.55	-0.08
ln(SO_x)	-0.34	0.18	-0.47	-0.52	-0.25
ln(CO_2/L)	0.40	-0.51	-0.13	-0.07	0.33
ln(NO_x/L)	-0.15	-0.10	-0.39	-0.50	-0.03
ln(SO_x/L)	-0.29	0.08	-0.47	-0.51	-0.24
ln(VA/L)	1	-0.56	-0.12	-0.36	0.25
ln(L)	-0.56	1	-0.15	-0.30	-0.21
TO_{EU15}*	-0.12	-0.15	1	0.66	-0.05
$TO_{extraEU15}$*	-0.36	-0.30	0.66	1	0.12
ln(R&D/VA)**	0.25	-0.21	-0.05	0.12	1

* Only for branches belonging to D and years 1995-2005

** Only for branches belonging to D and years 1991-2004

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

Table 3: Descriptive statistics (VA/L)

	Aggregate [29 branches] 1990-2007	Manufacturing [14 branches] 1990-2007	Services [9 branches] 1990-2007	Trade [14 branches] 1995-2005	R&D [14 branches] 1991-2004
Mean	61.66	52.33	49.25	53.92	53.80
St. deviation	66.22	38.81	22.61	38.58	354.94
Min	11.50	22.94	27.11	26.16	24.11
	(A, 1990)	(DD, 1990)	(H, 2004)	(DD, 1995)	(DB, 1991)
Max	528.50	261.85	112.35	261.85	261.85
	(CA, 2000)	(DF, 1995)	(K, 1990)	(DF, 1995)	(DF, 1995)
I decile	26.16	29.59	30.04	30.89	29.21
II decile	31.61	32.35	32.93	32.99	31.61
III decile	33.91	36.10	34.07	41.11	36.10
IV decile	38.68	41.57	38.36	43.65	41.40
V decile	41.79	43.50	40.21	45.49	43.07
VI decile	45.44	45.94	41.72	46.78	45.50
VII decile	48.45	47.35	47.65	47.00	46.87
VIII decile	63.69	49.56	68.20	49.47	48.74
IX decile	105.61	80.01	87.28	80.35	77.11

Table 4: Descriptive statistics (L)

	Aggregate [29 branches] 1990-2007	Manufacturing [14 branches] 1990-2007	Services [9 branches] 1990-2007	Trade [14 branches] 1995-2005	R&D [14 branches] 1991-2004
Mean	785.95	355.25	1594.10	349.96	354.94
St. deviation	797.66	211.56	804.00	207.22	207.97
Min	6	24	588	24	24
	(CA, 2000)	(DF, 2002)	(J, 2000)	(DF, 2002)	(DF, 2002)
Max	3660	918	3660	859	884
	(G, 1991)	(DJ, 2007)	(G, 1991)	(DJ, 2003)	(DB, 1991)
I decile	35	176	620	181	185
II decile	184	201	973	204	207
III decile	243	216	1232	214	226
IV decile	291	259	1404	255	259
V decile	474	276	1451	269	278
VI decile	630	319	1512	316	320
VII decile	1102	453	1574	450	446
VIII decile	1451	524	1666	531	508
IX decile	1603	695	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 2002-2007 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.

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)	0.4217***	2.9175***	-7.1328***	1.7503***	1.8175***	2.9543***
	[0.06]	[0.41]	[1.38]	[0.57]	[0.60]	[0.45]
[ln(VA/L)]^2		-0.2921***	0.8794***	-0.1682***	-0.1795***	-0.2974***
		[0.04]	[0.18]	[0.06]	[0.06]	[0.05]
Stagnation	0.0297**	0.0061	-0.0408**	0.0213	0.0237	0.0062
	[0.01]	[0.02]	[0.02]	[0.01]	[0.02]	[0.02]
	(103.01%)	(100.61%)	(96.00%)	(102.15%)	(102.40%)	(100.62%)
TO$_{EU15}$				-0.1168**		
				[0.05]		
TO$_{extraEU15}$					-0.0777*	
					[0.04]	
ln(R&D/VA)						0.0423***
						[0.02]
Constant	7.6412***	3.0138***	22.2152***	5.7825***	5.6371***	3.171***
	[0.22]	[0.94]	[2.65]	[1.32]	[1.38]	[1.06]
R^2 *(within)*	0.1674	0.2457	0.2240	0.0806	0.0642	0.3162
F test	34.53	20.25	17.39	3.92	3.18	23.32
Wald test for groupwise heterosk.	1967.29***	483.71***	774.99***	171.21***	194.12***	475.66***
*N*T*	522	252	162	154	154	196
Period	1990-2007	1990-2007	1990-2007	1995-2005	1995-2005	1991-2004
Turning point		147.397***	57.7188***	181.8205***	157.9046***	143.6112***
		[13.42]	[4.68]	[33.77]	[34.77]	[24.59]
Shape (VA/L)	Linear	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)	0.1474***	2.534***	-0.6131***	1.6209***	1.7749***	2.5547***
	[0.05]	[0.48]	[0.14]	[0.57]	[0.61]	[0.49]
[ln(VA/L)]^2		-0.2549***		-0.1568***	-0.1798***	-0.2589***
		[0.05]		[0.06]	[0.06]	[0.05]
ln(L)	0.3634***	0.7601***	14.8656***	0.7669***	0.6993***	0.6502***
	[0.07]	[0.13]	[2.74]	[0.17]	[0.17]	[0.15]
[ln(L)]^2			-0.9838***			
			[0.18]			
Stagnation	0.0412***	0.004	0.0352	0.0173	0.0223	0.0041
	[0.01]	[0.02]	[0.02]	[0.02]	[0.02]	[0.02]
	(104.21%)	(100.40%)	(103.58%)	(101.75%)	(102.26%)	(100.41%)
TO$_{EU15}$				-0.123**		
				[0.05]		
TO$_{extraEU15}$					-0.1045**	
					[0.05]	
ln(R&D/VA)						0.0384**
						[0.01]
Constant	12.511***	5.2807***	-38.3408***	7.4284***	7.5191***	6.0807***
	[0.51]	[1.66]	[10.15]	[1.71]	[1.71]	[1.79]
R^2 *(within)*	0.0857	0.1905	0.3506	0.2044	0.1973	0.2218
F test	14.55	9.74	15.22	8.18	7.74	10.50
Wald test for groupwise heterosk.	4112.99***	508.21***	583.02***	238.01***	292.63***	472.64***
*N*T*	522	252	162	154	154	196
Period	1990-2007	1990-2007	1990-2007	1995-2005	1995-2005	1991-2004
TP (VA/L)		144.114***		175.6966***	139.044***	139.0231***
		[14.85]		[34.29]	[32.34]	[26.13]
TP (L)			1910.541***			
			[136.36]			
Shape (VA/L)	Linear	Inverted U shape	Linear	Inverted U shape	Inverted U shape	Inverted U shape

Table 7: EKC models for NOx

	EKC 1 [aggr]	**EKC 2 [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)	-0.1162	-4.0365***	-9.4283***	0.1819	0.0304	-4.7249***
	[0.09]	[0.59]	[1.73]	[0.13]	[0.17]	[0.72]
$[ln(VA/L)]^2$		0.4262***	1.1451***			0.4532***
		[0.06]	[0.23]			[0.08]
Stagnation	-0.2503***	-0.1955***	-0.2482***	-0.1542***	-0.1327***	-0.2246***
	[0.02]	[0.02]	[0.03]	[0.02]	[0.02]	[0.03]
	(77.86%)	(82.24%)	(78.02%)	(85.71%)	(87.57%)	(79.88%)
TO_{EU15}				-0.2331		
				[0.15]		
$TO_{extraEU15}$					-0.241**	
					[0.10]	
ln(R&D/VA)						0.081***
						[0.03]
Constant	4.0755***	12.8506***	21.9591***	3.2045***	3.7375***	15.4935***
	[0.36]	[1.37]	[3.27]	[0.6]	[0.73]	[1.67]
R^2 (within)	0.2550	0.3831	0.3441	0.3564	0.3724	0.3924
F test	100.66	64.68	36.02	35.76	41.64	29.39
Wald test for groupwise heterosk.	3925.54***	981.52***	1444.70***	378.18***	343.93***	385.24***
*N*T*	522	252	162	154	154	196
Period	1990-2007	1990-2007	1990-2007	1995-2005	1995-2005	1991-2004
Turning point		113.9758***	61.3609***			183.6485***
		[16.49]	[5.58]			[58.44]
Shape (VA/L)	No significant relation	U shape	U shape	No significant relation	No significant relation	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)	-1.0393***	-4.013***	-1.1741***	0.155	-0.0518	-4.5631***
	[0.37]	[0.61]	[0.19]	[0.13]	[0.19]	[0.77]
$[ln(VA/L)]^2$	0.0804*	0.4239***				0.4376***
	[0.04]	[0.07]				[0.09]
ln(L)	0.4706***	1.0147***	-0.8293***	0.6895**	0.4571*	1.1417***
	[0.12]	[0.15]	[0.21]	[0.27]	[0.25]	[0.26]
$[ln(L)]^2$						
Stagnation	-0.2318***	-0.1954***	-0.0408	-0.1597***	-0.1351***	-0.2238***
	[0.02]	[0.02]	[0.04]	[0.02]	[0.02]	[0.03]
	(79.31%)	(82.25%)	(96.00%)	(85.24%)	(87.36%)	(79.95%)
TO_{EU15}				-0.2436		
				[0.15]		
$TO_{extraEU15}$					-0.2893***	
					[0.11]	
ln(R&D/VA)						0.0826***
						[0.03]
Constant	9.5743***	12.7115***	20.5235***	5.0673***	7.1468***	14.3149***
	[1.11]	[1.80]	[1.99]	[1.79]	[1.90]	[2.51]
R^2 (within)	0.3395	0.5193	0.2840	0.4253	0.4521	0.4928
F test	54.76	74.45	21.73	30.07	33.97	31.87
Wald test for groupwise heterosk.	3790.98***	986.24***	430.89***	339.42***	569.60***	355.91***
*N*T*	522	252	162	154	154	196
Period	1990-2007	1990-2007	1990-2007	1995-2005	1995-2005	1991-2004
TP (VA/L)	640.2201	113.7232***				183.8304***
	[899.56]	[15.98]				[61.16]
TP (L)						
Shape (VA/L)	U shape	U shape	Linear	No significant relation	No significant relation	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)	-6.7523***	-13.7499***	-31.6456***	-11.3117***	-10.1243***	-13.7675***
	[1.48]	[1.48]	[7.78]	[3.12]	[3.84]	[1.66]
[ln(VA/L)]^2	0.6331***	1.3635***	3.818***	1.0899***	0.921**	1.3317***
	[0.17]	[0.16]	[1.01]	[0.32]	[0.42]	[0.18]
Stagnation	-1.2564***	-0.9406***	-1.1616***	-0.6313***	-0.5924***	-0.7153***
	[0.07]	[0.07]	[0.11]	[0.07]	[0.07]	[0.07]
	(28.47%)	(39.04%)	(31.30%)	(53.19%)	(55.30%)	(48.90%)
TO$_{EU15}$				-0.9712***		
				[0.25]		
TO$_{extraEU15}$					-0.7585**	
					[0.37]	
ln(R&D/VA)						0.0091
						[0.05]
Constant	18.8188***	35.701***	65.2859***	31.264***	28.8403***	36.2791***
	[3.20]	[3.34]	[15.00]	[7.24]	[8.46]	[3.80]
R^2 *(within)*	0.5500	0.6841	0.927	0.5402	0.5258	0.5798
F test	222.30	163.87	45.93	42.49	40.88	66.90
Wald test for groupwise heterosk.	663.28***	90.52***	150.58***	23.18*	34.40***	107.85***
*N*T*	522	252	162	154	154	196
Period	1990-2007	1990-2007	1990-2007	1995-2005	1995-2005	1991-2004
Turning point	206.9546***	154.812***	63.0702***	179.3465***	243.8618**	175.7433***
	[66.86]	[11.99]	[7.35]	[25.24]	[116.25]	[23.45]
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)	-9.943***	-14.0742***	-4.0103***	-11.1789***	-10.1606**	-15.0835***
	[1.77]	[1.70]	[0.82]	[3.17]	[3.90]	[1.71]
[ln(VA/L)]^2	1.02***	1.395***		1.0782***	0.9207**	1.4586***
	[0.19]	[0.18]		[0.32]	[0.42]	[0.18]
ln(L)	6.7225***	0.7972*	-4.8604***	1.2392	0.7438	-0.1523
	[1.18]	[0.48]	[0.66]	[0.96]	[0.89]	[0.61]
[ln(L)]^2	-0.5244***					
	[0.10]					
Stagnation	-1.1565***	-0.9424***	-0.4979***	-0.6273***	-0.5935***	-0.7221***
	[0.08]	[0.07]	[0.13]	[0.07]	[0.07]	[0.07]
	(31.46%)	(38.97%)	(60.78%)	(53.40%)	(55.24%)	(48.57%)
TO$_{EU15}$				-0.9649***		
				[0.25]		
TO$_{extraEU15}$					-0.7813**	
					[0.39]	
ln(R&D/VA)						-0.0038
						[0.05]
Constant	10.7452**	37.6178***	58.3389***	29.575***	30.4437***	45.8628***
	[4.97]	[5.79]	[7.11]	[10.16]	[10.16]	[6.21]
R^2 *(within)*	0.5883	0.7075	0.5467	0.5590	0.5452	0.6097
F test	143.08	137.23	52.97	35.38	33.87	61.31
Wald test for groupwise heterosk.	682.37***	95.19***	839.63***	22.33*	34.38***	114.34***
*N*T*	522	252	162	154	154	196
Period	1990-2007	1990-2007	1990-2007	1995-2005	1995-2005	1991-2004
TP (VA/L)	130.8302***	155.1796***		178.4055***	249.1099**	175.9916***
	[18.78]	[11.89]		[25.66]	[125.53]	[20.35]
TP (L)	608.0011**					
	[233.91]					
Shape (VA/L)	U shape	U shape	Linear	U shape	U shape	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				Stagn.	Stagn. (%)	Constant
					Min	Year	Max	Year			
DA	1.9322***		Linear		37.9856	1990	47.9483	2000	0.2281***	125.62%	2.3028***
	[0.19]								[0.04]		[0.71]
DB	19.5298***	-2.7844***	Inverted U	33.3489***	23.3356	1990	34.7757	2000	-0.0777**	92.53%	-24.5370***
	[2.24]	[0.33]	shape	[0.53]					[0.04]		[3.82]
DC	42.6503***	-6.1794***	Inverted U	31.5325***	25.1107	1991	33.8144	2006	0.0078	100.78%	-65.0232***
	[2.90]	[0.42]	shape	[0.15]					[0.03]		[4.96]
DD	21.2482***	-3.0915***	Inverted U	31.0788***	22.9393	1990	32.9893	2001	-0.0213	97.90%	-27.7188***
	[2.50]	[0.37]	shape	[0.42]					[0.03]		[4.18]
DE	-24.0853*	3.4071**	U shape	34.2808***	40.9460	1990	51.4569	2001	0.1055***	111.13%	52.1069**
	[13.23]	[1.73]		[5.06]					[0.03]		[25.29]
DF	0.0904***		Linear		89.0769	2006	261.8504	1995	0.0773**	108.04%	13.2207***
	[0.03]								[0.03]		[0.14]
DG	27.1527***	-3.2610***	Inverted U	64.2800***	56.9961	1990	82.7129	2004	-0.1007***	90.42%	-45.0600***
	[7.65]	[0.90]	shape	[1.52]					[0.03]		[16.16]
DH	50.8946***	-6.6477***	Inverted U	45.9685***	40.1250	1990	50.5949	2007	0.0283	102.87%	-87.9360***
	[5.17]	[0.68]	shape	[0.27]					[0.02]		[9.88]
DI	-31.6595***	4.3567***	U shape	37.8437***	37.1304	1991	50.5403	2006	-0.0048	99.52%	69.3629***
	[4.11]	[0.55]		[0.69]					[0.02]		[7.72]
DJ	45.0740***	-6.2806***	Inverted U	36.1735***	32.6544	1990	44.2821	2007	-0.1492***	86.14%	-70.3799***
	[8.81]	[1.21]	shape	[0.52]					[0.04]		[16.05]
DK	108.5946***	-13.9184***	Inverted U	49.4578***	42.1909	1993	52.2848	2007	-0.0258	97.45%	-203.0435***
	[16.04]	[2.08]	shape	[0.48]					[0.05]		[30.92]
DL	34.7111***	-4.3352***	Inverted U	54.7858***	37.3763	1990	49.2068	2001	-0.0125	98.75%	-61.0416***
	[4.37]	[0.57]	shape	[1.52]					[0.03]		[8.30]
DM	-61.6571***	8.1705***	U shape	43.5165***	38.0214	1993	47.1088	2000	0.0521	105.35%	125.6211***
	[20.13]	[2.68]		[0.60]					[0.04]		[37.84]
DN	56.4478***	-7.9369***	Inverted U	35.0237***	28.9083	1991	36.1094	2000	0.0486**	104.98%	-92.1213***
	[4.60]	[0.66]	shape	[0.24]					[0.02]		[8.03]

Breusch-Pagan test of independence (Chi 2): 214.645***

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	-57.6699***	7.5075***	U shape	46.5628***	37.9856	1990	47.9483	2000	0.0378	103.85%	114.2188***
	[8.95]	[1.19]		[0.65]					[0.06]		[16.86]
DB	-12.5470***	1.6383***	U shape	46.0317***	23.3356	1990	34.7757	2000	-0.1562***	85.53%	27.0182***
	[3.86]	[0.57]		[7.36]					[0.05]		[6.52]
DC	-0.6563***		Linear		25.1107	1991	33.8144	2006	-0.4099***	66.37%	4.9263***
	[0.11]								[0.06]		[0.36]
DD	21.3847***	-3.3000***	Inverted U shape	25.5373***	22.9393	1990	32.9893	2001	-0.2238***	79.95%	-31.4137***
	[5.32]	[0.80]		[0.69]					[0.03]		[8.86]
DE	89.2718***	-11.4013***	Inverted U shape	50.1481***	40.9460	1990	51.4569	2001	-0.0189	98.12%	-171.7928***
	[23.61]	[3.08]		[1.27]					[0.04]		[45.21]
DF	0.5768***		Linear		89.0769	2006	261.8504	1995	-0.0868	91.69%	4.3915***
	[0.06]								[0.06]		[0.31]
DG	138.7384***	-16.9180***	Inverted U shape	60.3591***	56.9961	1990	82.7129	2004	0.1037	110.92%	-278.6528***
	[17.76]	[2.09]		[1.14]					[0.09]		[37.64]
DH	-59.8654***	7.6138***	U shape	50.9778***	40.1250	1990	50.5949	2007	-0.2364***	78.95%	120.9222***
	[14.59]	[1.92]		[1.88]					[0.07]		[27.70]
DI	-14.0131***	1.8926***	U shape	40.5309***	37.1304	1991	50.5403	2006	-0.0655***	93.66%	32.0125***
	[5.02]	[0.67]		[1.11]					[0.02]		[9.43]
DJ	55.0870***	-7.7388***	Inverted U shape	35.1335***	32.6544	1990	44.2821	2007	-0.2081***	81.21%	-94.0315***
	[11.34]	[1.55]		[0.84]					[0.07]		[20.75]
DK	85.3716***	-11.0890***	Inverted U shape	46.9643***	42.1909	1993	52.2848	2007	-0.2639***	76.80%	-161.3671***
	[11.79]	[1.53]		[0.29]					[0.03]		[22.74]
DL	43.4205***	-5.7153***	Inverted U shape	44.6389***	37.3763	1990	49.2068	2001	-0.2679***	76.50%	-79.9307***
	[5.18]	[0.68]		[0.24]					[0.02]		[9.85]
DM	-15.8932***	1.8636***	U shape	71.1084***	38.0214	1993	47.1088	2000	-0.0570**	94.46%	36.3905***
	[5.33]	[0.71]		[13.20]					[0.03]		[10.05]
DN	31.7782***	-4.6298***	Inverted U shape	30.9350***	28.9083	1991	36.1094	2000	-0.2915***	74.71%	-51.7383***
	[6.49]	[0.93]		[0.50]					[0.02]		[11.34]

Breusch-Pagan test of independence (Chi 2): 189.464***

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**				**Stagn.**	**Stagn. (%)**	**Constant**
					Min	**Year**	**Max**	**Year**			
DA	-57.4608*	7.1327*	U shape	56.1462***	37.9856	1990	47.9483	2000	-0.7798***	45.85%	118.4204**
	[29.52]	3.920886		[8.31]					[0.14]		[55.56]
DB	64.2990***	-9.9448***	Inverted U shape	25.3505***	23.3356	1990	34.7757	2000	-1.1637***	31.23%	-99.8892***
	[11.11]	[1.66]		[0.60]					[0.14]		[18.61]
DC	29.8466***	-4.8478***	Inverted U shape	21.7229***	25.1107	1991	33.8144	2006	-1.2403***	28.93%	-42.8211**
	[11.29]	[1.66]		[2.46]					[0.20]		[19.20]
DD	53.4649***	-8.9030***	Inverted U shape	20.1385***	22.9393	1990	32.9893	2001	-0.9832***	37.41%	-76.6155***
	[13.16]	[1.97]		[1.52]					[0.12]		[21.95]
DE	209.7934***	-28.2158***	Inverted U shape	41.1678***	40.9460	1990	51.4569	2001	-0.8266***	43.75%	-387.3852***
	[47.33]	[6.19]		[1.01]					[0.12]		[90.41]
DF	5.0084*	-0.4366*	Inverted U shape	309.5307**	89.0769	2006	261.8504	1995	-0.4124***	66.21%	-5.2528
	[2.58]	0.2557		[128.84]					[0.11]		[6.50]
DG	158.3384***	-19.2098***	Inverted U shape	61.6395***	56.9961	1990	82.7129	2004	-0.7181***	48.77%	-319.8501***
	[31.06]	[3.67]		[1.40]					[0.15]		[65.61]
DH	-6.7258***		Linear		40.1250	1990	50.5949	2007	-1.0661***	34.44%	28.6757***
	[0.74]								[0.25]		[2.82]
DI	-20.5173***	2.6725***	U shape	46.4623***	37.1304	1991	50.5403	2006	0.0384	103.92%	44.6559***
	[7.69]	[1.02]		[1.73]					[0.03]		[14.44]
DJ	109.0876***	-15.2861***	Inverted U shape	35.4523***	32.6544	1990	44.2821	2007	-0.2393**	78.72%	-190.4793***
	[15.62]	[2.15]		[0.46]					[0.10]		[28.38]
DK	238.2910***	-31.6310***	Inverted U shape	43.2385***	42.1909	1993	52.2848	2007	-1.2145***	29.69%	-446.5502***
	[28.20]	[3.66]		[0.53]					[0.16]		[54.33]
DL	158.0696***	-21.4023***	Inverted U shape	40.1576***	37.3763	1990	49.2068	2001	-1.0974***	33.37%	-290.1629***
	[23.46]	[3.10]		[0.60]					[0.15]		[44.34]
DM	216.2796***	-29.5874***	Inverted U shape	38.6647***	38.0214	1993	47.1088	2000	-1.1411***	31.95%	-393.2317***
	[32.46]	[4.30]		[0.74]					[0.20]		[61.21]
DN	-5.2260***		Linear		28.9083	1991	36.1094	2000	-1.3735***	25.32%	20.1299***
	[0.39]								[0.20]		[1.38]

Breusch-Pagan test of independence (Chi 2): 490.630***

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)	2.7429***	-3.8361***	-11.9045***
	[0.09]	[0.14]	[0.48]
[ln(VA/L)]^2	-0.2748	0.4095***	1.1855***
	[0.01]	[0.02]	
Stagnation	-0.0105**	-0.1903***	-0.8875***
	[0.01]	[0.01]	[0.05]
	(101.06%)	(82.67%)	(41.17%)
Breusch-Pagan test of independence (Chi^2)	488.022***	412.214***	652.702***
Test of aggregation bias (Chi^2)	5390.40***	12024.73***	4069.00***
*N*T*	252	252	252
Period	1990-2007	1990-2007	1990-2007
Turning point	147.0175***	108.1775***	151.5577***
	[3.29]	[3.46]	[2.80]
Shape (VA/L)	Inverted U shape	U shape	U shape