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THE DYNAMICS OF DELINKING IN INDUSTRIAL EMISSIONS: THE ROLE OF PRODUCTIVITY, TRADE AND R&D [1]

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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. Environmental innovative capacity is currently the key issue for long term sustainability. In fact, environmental innovations are particularly crucial in industrial frameworks since they often give rise to a double externality, providing on the one hand the typical R&D spillovers and on the other hand reducing environmental externalities. They provide a contribution to the Lisbon Objectives on growth and innovation and the

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Gothenburg priorities on sustainable development complementarities. Actually, in the current situation the "two crises" (economic-financial and environmental) can be coherently and jointly tackled insofar as (green) investments may lead to Keynesian increases in demand and a reshaping of the economy along a greener basis. Integrated (eco) product and process innovations, that need high R&D expenses contrary to end-of-pipe solutions, may end up with restructuring production processes and achieve the double dividend of integrating labour productivity and environmental efficiency increases along the dynamic path, mitigating the usual trade-offs that exist between environmental and economic aims, especially when facing global public good issues such as climate change. The positive correlation between labour and environmental productivities is then the pre-condition for stronger competiveness and sustainability in the long run; innovation is in other words the key to providing private and public benefits. It is obvious that the more innovation is radical the more it is probably costly in the short term. This paper especially focuses on the link between environmental performances and labour productivity by adopting a sector and dynamic lens. Innovation is not the primary focus but, as commented on, is a more or less latent factor that we conceptually deal with and attempt to include as far as possible from both theoretical and empirical perspectives.

The value of this mainly empirical paper is manifold. First, its originality lies in the very rich NAMEA sector based economic-environmental merged dataset for 1990-2005, 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 relatively 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, NOx and PM_{10} [2]. In addition to core evidence on the EKC shape, we test the following hypotheses: (a) whether the increasing trends associated with trade openness among EU_{15} and non-EU_{15} countries affect emission dynamics, following the "pollution haven" debate (Cole 2003, 2004; Cole and Elliott, 2002; Copeland and Taylor, 2004); (b) whether pre-Kyoto and post-Kyoto dynamics show different empirical structures; (c) whether sector R&D plays a role in explaining emissions efficiency.

The policy relevance of this work lies in: (1) the temporal structural break in pre-Kyoto and post-Kyoto dynamics; and (2) the possibility of investigating inside the branch dynamics that could help to shape EU policies such as refinements to existing Emission Trading Scheme (ETS), or a new carbon tax for specific sectors. The use of NAMEA, which is a panel of observations

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[2] Particulate matter smaller than 10 microns.

for air emissions, value added and employment matched for the same productive branches of the economy (Femia and Panfili, 2005), is a novelty of our study, compared to other international studies on EKC. We use a disaggregation at 15 productive branches for manufacturing and energy production and 4 air emissions.

The paper is structured as follows. Section 2 outlines the main methodological and theoretical issues. Section 3 presents and discusses our dataset and methodology. Section 4 presents the main findings for the four air emissions. Section 5 concludes.

ECONOMIC GROWTH, ENVIRONMENTAL EFFICIENCY AND INNOVATION WITHIN DELINKING ANALYSES

Our discussion of some of the approaches to studying delinking begins within a simple IPAT framework that we then use as well as the EKC model for our empirical investigation. 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 disaggregation 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) need 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 to “produce” one unit ($1) 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. Thus T can be directly examined in the delinking analysis by using diverse proxies determined by research hypotheses and data availability. $P \bullet A$, which is conceptually equivalent to consumption, and T are the main “control variables” in the system.

Within an IPAT framework, three aspects of "delinking analysis" and "EKC analysis" emerge. The IPAT may in fact be a fruitful sketched framework within which reasoning may take place around the key relationship for sustainable economic development: the influence of (radical) innovations on environmental performances, that is here analysed embedded in models that specify labour productivity as core dynamics.

In a nutshell, higher environmental efficiency (either lower emissions or lower emissions per unit of value that are captured in EKC and STIRPAT models) is stimulated by new technological options that shift to less impacting energy sources or increase utilisation efficiency of a defined (renewable or not) energy input. Both incremental and radical types of innovations can lead to sustainable paths. The key fact is the long-run net present value of different innovation paths. The risk is to "choose" an option that drives and eventually lock-in the dynamics, if technological development irreversibility and fixed cost are high – which is likely for major innovation changes – towards second best or third best technological alternatives. Reasons may depend on mere analysis of static efficiency, inter-temporal myopia, or partial accounting of shadow prices among others. An example is the possible choice of still useful and environmentally effective, but already mature technologies, or even end-of-pipe technologies – that do not imply restructuring of the entire production process impacting jointly on labour and environmental productivity. Such choices may be less costly now but less effective in the long run if compared to less mature but more costly technologies. (Del Rio Gonzalez, 2008) This key example shows on the one hand the absolute relevancy of dealing with innovation, and its effects and drivers, along a co-evolutionary dynamic scenario, and on the other hand that necessary innovation dynamics are stimulated by various drivers, such as firms' social responsibility (CSR) going beyond mere compliance (Portney, 2008; Lyon and Maxwell, 2008), recalling the well known Porter hypothesis (see also below). R&D investments are surely needed for radical innovation changes, as well as environmental and innovation policies that complement and stimulate firm actions, and the eventual complementarities among drivers. (Mazzanti and Zoboli, 2009b, 2008) R&D and CSR are joint factors that co-evolve with economic performance – profitability and productivity – highlighting the key role of economic drivers, and are also affected by sector – and firm – based idiosyncratic elements. In addition, drivers should target the most efficient elements in a long run environmental-economic perspective, given that market failures characterise both innovation and environmental realms. For example, subsidies may complement other economic instruments such as eco-taxes for both changing relative prices and sustaining niche innovation markets until the best technology is sufficiently mature and diffused, with economies of scale in action at both supply and demand sides of the market. The role of innovation and economic performance, and their relationships, is thus central in a theoretical framework that sets out to explain the extent to which and for what reasons environmental performance is changing and eventually improving over time.

Sector data analyses, though deficient with respect to the possibility of investigating detailed innovation factors, offer higher generality since they present evidence on country or larger areas, still rooted in crucial sector heterogeneity that characterises environmental, innovation and economic performances. We here use, as commented below, R&D sector data merged with NAMEA data. R&D is a key input innovation factor that is useful since it should correlate to more radical and integrated greener processes. We do not investigate R&D drivers, an analysis lying beyond our research scope. The two most significant values added in future research are, in our eyes, the integration of sector and firm levels to exploit relative pros and mitigate cons, and the definition of environmentally based sector innovation data (eco-innovations, green R&D).

Let us comment on specifically different parts of the IPAT argument. 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 if they say nothing about the role of economic drivers and embedded innovation dynamics. An environmental impact growing more slowly than economic drivers is generally described as "relative delinking". "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. A multivariate setting is needed to capture robust relative influences on I.

Second, an eventual 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 apply to a dynamic setting. The theory and evidence suggests that if T refers to a key resource such as energy, then T can depend on energy strategies and innovation choices that are activated through, and thus may also endogenously depend on, GDP or GDP/P, and *vice versa*. In a dynamic setting, I can be a driver of T. In fact 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". But, improvements in T for a specific I can also stem from general techno-economic changes, e.g. "dematerialisation" associated with ICT diffusion, which are not captured by resource-specific "induced innovation" mechanisms (through the re-discovery of the Hicksian "induced innovation" hypothesis in the environmental field), and can vary widely for given levels of GDP/P depending on the different innovativeness of similar countries. Then, a decrease in T can be related to micro- and macro- non-deterministic processes that also involve dynamic feedbacks, for which economics proposes a set of open interpretations.

Third, EKC analysis addresses some of the above relationships, i.e. between I and GDP or between T and GDP/P, by looking at the direct/indirect "benefits" and "costs" of growth in terms of environmental impact. Even though it may highlight empirical regularities that are of heuristic value, it does not directly provide economic explanations. The existence of an EKC could deterministically be misleading in suggesting that rapid growth towards high levels of GDP/P automatically produces greater environmental efficiency and thus growth can be the "best policy strategy" to reduce environmental impact.

The link between environmental efficiency and economic performance is relevant in determining the drivers of T and hence the innovative objectives of the economic agents. Recently, the theoretical and empirical literature has focused on the assessment of the complementarities between the two performances. Until the paper of Porter and van der Linde (1995), the general idea was that the fulfilment of environmental regulation[3] would reduce the competitiveness of the hit sectors/firms. On the contrary, the so-called "Porter hypothesis" revealed the potential complementarities and (private) beneficial effects of properly designed environmental regulations. In a competitive framework characterized by dynamic efficiency, incomplete information, complexity and uncertainty, private benefits of environmental innovations could remain unexploited. While in some cases environmental regulations are necessary, for other cases information about promising paths of innovation is sufficient (e.g. "early mover advantages"). A first example, based on the classical concept of (static) efficiency, considers the saving of material inputs due to a more eco-efficient production process. A second example, now in a framework of dynamic efficiency, is linked to "early mover advantages". The adoption of eco-efficient processes in advance respect to competitors creates an economic advantage at the moment when an environmental regulation is introduced. The advantage comes from the inertia of competitors in the adaptation to new environmental standards. Finally, it is worth noting that in general, ecological and economic innovations could not be separated. So, ecological innovations could be a "by-product" of economic ones.

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[3] Or, alternatively, the improving *per se* of environmental performance.

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, policy implementation and policy effectiveness. The value of country-based delinking evidence is high. NAMEA-structured studies could provide great value added for the policy arena as well as contributing to the EKC economic debate. (List and Gallet, 1999) Some stylised facts might help. Concerning GHGs and other air polluting emissions, the empirical literature 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. Despite this partially positive evidence, reductions are largely heterogeneous by country and sector. We thus argue that specific in-depth country evidence would be helpful to inform both national policies and, e.g. the core Clean Air For Europe (CAFE) programme, and the implementation of the EU ETS and its modification.

EMPIRICAL MODEL AND DATA SOURCES

Models and research hypotheses

EKC oriented specifications

We test two models; the first uses the EKC framework as a reference (Mazzanti et al., 2008 for a similar formulation) while the second is a modified STIRPAT model. [4]

We reformulate the EKC relationship to exploit the sector-level disaggregation of NAMEA. We lose standard demographic and income information, but we can take advantage of insights on economic and environmental efficiencies in the production process. Equation (1) shows the EKC based empirical model:

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

In equation (1) *environmental technical efficiency* (emissions/full-time equivalent jobs) is a function of a third order polynomial of labour productivity (in terms of value added per full-time equivalent job), individual (sector) dummy variables (β_{0i}) and a temporal structural break (Kyoto), coded 0 for 1990-1997 and 1 for 1998-2005. Logarithmic form of the dependent and

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[4] STIRPAT is “Stochastic Impacts by Regressions on Population, Affluence and Technology”.

explanatory variables enables the estimated coefficients to be interpreted as elasticity.

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

Individual effects (β_{0i}) capture the specific features of the branch in terms of average emissions intensity. We estimate these individual effects using a fixed effects model (FEM) following Wooldridge (2005). [5] In addition to the core specification, we design a sort of "Kyoto" structural break by means of a dummy variable to try to capture direct or indirect effects of the Kyoto Protocol. Direct effects should be GHG (CO2) emissions reductions in response to policies introduced to meet the Kyoto target. Indirect effects will be related to anticipatory strategies for future policies on GHGs and, for pollutants, from ancillary benefits of GHG emissions reductions. [6] We can state, therefore, in addition to specific Kyoto-related effects, that this dummy variable captures temporal variations in emissions linked to various policy effects in EU and Italian environments, and other temporal changes common to all the branches. The antilog of β_1 can be viewed as the average level of emissions *ceteris paribus* in 1998-2005, with average emissions levels in 1990-1997 equal to 1.

We first extend the base model by adding two *trade openness indexes*, one for EU_{15} and one for the extra-EU_{15} area. Because of the high level of correlation between the two "openness indexes" (0.7696) we analyse them separately to overcome potential collinearity problems.

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

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

For a review of the theoretical reasoning behind the link between trade openness and emissions growth, we refer among others to Zugravu et al. (2008), Frankel and Rose (2005), Cole (2003, 2004), Cole and Elliott (2002), Dietzenbacher and Mukhopadhay (2006) and Mazzanti et al. (2008). The sign of the relationship depends on two potentially conflicting forces: the delocalisation of polluting industries into 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 with *pollution haven* effects on the basis of the growing homogeneity of European environmental policies. We can expect then either an insignificant or a negative effect on emissions. EU environmental policies explicitly take account of and correct for potential intra-EU unwanted and harmful for 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. Communitarian openness, apart from race-to-the-top effects, is related to intra-sector specialisation in response to relative abundance/scarcity of factors endowment (linked to particular environmental pressures) and the spread of environmentally efficient technologies.

Extra-EU_{15} openness instead captures the balance between the *factor endowment* and *pollution haven* effects. Italy is expected to have a comparative advantage in capital (and then pollution) intensive production 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.

Finally, we test the effect of R&D/VA, in order to evaluate whether the innovative efforts of enterprises could have a beneficial or negative effect on environmental efficiency[7]. Generally, the adoption of process/product innovations occurs with a delay as a consequence of R&D investments. We

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[7] We do not test in a single equation R&D and TO indexes because, by so doing we have a reduction of T (which is already low for TO estimates) and an increase of the tested parameters, with a further reduction of the degrees of freedom and then robustness.

use a contemporary R&D/VA ratio because if we use lags we lose too many observations. [8]

STIRPAT based specifications

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

We start from a revised IPAT identity, as described in equations 2-4 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).

$$E = L * (VA / L) * (E / VA) \tag{2}$$

$$E_{it} = \beta_{0i} * (L_{it})^{\beta_1} * (VA_{it} / L_{it})^{\beta_2} * (E_{it} / VA_{it})^{\beta_3} * e_{it} \tag{3}$$

$$\begin{aligned} \ln(E_{it}) = {} & \beta_{0i} + \beta_1 Kyoto_{0,1} + \beta_2 \ln(VA_{it} / L_{it}) + \beta_3 [\ln(VA_{it} / L_{it})]^2 + \beta_4 [\ln(VA_{it} / L_{it})]^3 + \\ & + \beta_5 \ln(L_{it}) + \beta_6 \ln(L_{it})^2 + \varepsilon_{it} \end{aligned} \tag{4}$$

The above stochastic reformulation of equation (2) has some interesting features. Firstly, it allows separate investigation of the relationship between environmental pressures and employment. Secondly, it 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 empirical assessment of labour dynamics associated with technological developments, 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

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[8] The merging of R&D and NAMEA data sources is a worthwhile value added exercise. We are aware that both R&D expenditures are somewhat endogenous with respect to value added in a dynamic scenario. Two stage 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 sufficiently disaggregated level. Only microeconomic data and evidence on environmental innovation processes are available.

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

We maintain the third order polynomial form for labour productivity and add the squared term of employment to test for non-linearities. Individual effects, Kyoto 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. Total emissions may be more relevant for effective sustainability assessment, provided that policy targets are defined in total terms. The interpretation of the coefficients of employment varies depending on an increasing or decreasing level of labour In presence of increasing employment, we observe an emissions saving effect when emissions increase less than proportionally with respect to employment (or even decrease) (elasticity <1). A more than proportional increase 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.

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.

The data

We tested EKC and STIRPAT models for four of the GHG and air pollutant emissions[10] included in NAMEA for Italy, using panel data disaggregated at sector level. In this paper we focus on industry (manufacturing (D) and energy (E) branches) for three main reasons. The first is linked to the economic and environmental relevance of industrial branches, which accounted in 2005 for 34.21% of output, 20.67% of value added, 20.97% of employment, 74.91% of CO_2 emissions, 37.85% of NOx emissions, 81.79% of SOx emissions and 34.47% of PM_{10} emissions. The second concerns the stronger innovatory content of industrial branches with respect to services. The third derives from the policy relevance of industry in terms of both ex-post assessment (the first Kyoto period) and for reasoning on current and future policy implementations (e.g. EU ETS, CAFE and so-called "20-20-20" EU strategy). Additional

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

[10] CO_2 for GHGs; SOx, NOx and PM_{10} for air pollutants. Estimates for CH_4 are not shown but are available upon request.

drivers of emissions intensity are then included in order to control the robustness of main specifications and investigate further theoretical hypotheses.

We use NAMEA tables for Italy for the period 1990-2005, allowing branch disaggregation at the 2-digit Nace (Ateco) classification level. In NAMEA tables, environmental pressures and economic data (output, value added [11], final consumption expenditures and full-time equivalent job) are assigned to the economic branches of resident units or to the household consumption categories directly responsible for environmental and economic phenomena. We use only data on industrial economic branches with a disaggregation of 15 branches. The added value of using environmental accounting data comes from the definitional internal coherence and consistency between economic and environmental modules.

We exploit the possibility of extending the basic NAMEA by the addition of foreign trade data: for each branch, import and export of the items directly related to the output of the branch are included (CPAteco classification). Data on national accounting for foreign trade are available from supply (import) and use (export) tables at the 2-digit level of CPAteco classification (51 items) for the period 1995-2004. Istat also produces COEWEB, a very detailed database on Italian foreign trade: time series 1991-2005 of external trade are available at the 4-digit level of CPAteco classification for A to E capital letters (agricultural sector and industry except F), with a disaggregation for the area (EU_{15}, EU_{25}, EU_{27} or extra-EU_{15}) of the partner. Unfortunately we cannot exploit that database consistently because, for privacy protection reasons, Istat does not publish data for branches with less than three units. However, we use the distinctions between EU_{15} – extra-EU_{15} trade as a weighting to split national accounting data. We construct trade openness indicators dividing the sum of imports and exports of every CPAteco category by the value added [12] of the corresponding Nace branch.

We also merge NAMEA tables with ANBERD [13] OECD Database containing R&D expenditures of enterprises for 19 OECD countries, covering the period 1987-2003 [14]. Enterprises' expenditures are disaggregated according to the ISIC Rev. 3 standard, which is not perfectly compatible with Nace classification because it excludes units belonging to institutional sectors different from private enterprises. We use the R&D/VA ratio to derive information on the relative measure of innovative effort of the different branches

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

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

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

[14] For Italy only 1991-2003.

and to get an index in constant prices. Figures 1-3 depict the observed dynamics on which we focus.

EMPIRICAL EVIDENCE

We comment on the main results of various empirical analyses focusing first on CO_2 and then on pollutants such as SOx, NOx and PM_{10}.

CO_2 emissions

EKC specifications

The evidence for CO_2 (Table 3) signals an inverted-U relationship, with a TP exceeding the range of VA/L. The average elasticity of emissions efficiency with regard to labour productivity in the linear specification (not shown) is 0.4025, highlighting a relative delinking that confirms our expectations. This outcome is as expected given that Italy is still lagging behind the Kyoto target at aggregate level and even focusing on the more innovation-intense and regulated parts of the economy such as industry [15]. Focusing on the "Kyoto structural break" in the series (pre and post 1997), CO_2 presents quite clear evidence: the dummy presents a positive sign. It seems, therefore, that neither the Kyoto emergence nor the 2003 Italian ratification has had significant effects on CO_2 emissions performance by the main emitters, industrial sectors. Industry has failed massively to adapt to the new climate change policy scenario, and even Italian environmental policy as a whole has somewhat lagged behind other leading countries in terms of policy efforts [16]. Future assessments, e.g. of the EU ETS scheme operative since 2005 in EU (Alberola et al., 2009; Smith and Swierzbinski, 2007), would provide subjects for further research [17]. Nevertheless, the evidence is

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[15] 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 EU_{27}. Current GHGs emissions are 10% higher than the Kyoto target (-6.5% for Italy), and are estimated to be in between +7.5% and -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.

[16] The Italian carbon tax proposal of 1999 was never implemented.

[17] 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 payments) 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 (DA), pottery, glass (DI) and steel (DJ). The test of the EKC model separately for those branches highlights the bad performance of paper (elasticity above unity), a smaller delinking in comparison with the industry for pottery and glass (elasticity < 1 but > 0.5) and a robust absolute delinking for steel.

as expected and, in part (in addition to the main sources of private transport, household emissions and services, not presenting delinking as well, even of relative nature), a reason for the lack of absolute delinking regarding CO_2 in the Italian industrial macro-sector so far.

Moving on to the results for trade openness and R&D, we note that trade openness factors (neither for EU_{15} nor extra-EU_{15}) emerge as significant. This may be due to the compensating and opposite effects (pollution haven and capital abundance) of trade on emissions, an explanation proposed by several authors who also found not (very) significant relationships.

R&D[18] is hardly relevant: a very weak 10% statistical significance emerges for CO_2, with a positive partially counter-intuitive sign. This result may reflect the weak eco-innovation content of, and low environmental expenditure on, process innovation dynamics in Italian industries, at least on average, and the end of the conceptual nature of most eco processes that have been implemented so far. Economic significance is also low: the coefficient is negligible. We refer to what we said above about the need for further investigation of the relationship using specific environmental innovation data at sector level.

STIRPAT specifications

In this type of analysis we refer to the effects on total emissions, as stated. Table 3 sums up the main regressions related to comments in the text. The evidence on the income-environment relationship is quite similar to what we commented just above. Only relative delinking is present.

The main evidence from the STIRPAT framework relates to the "emissions-labour relationship", which is implicitly defined in EKC model. We note first that the average employment trend, as in other countries, is decreasing for industry. The estimated elasticity is positive (0.47), denoting a "labour saving" interpretation: emissions decrease less than employment in industry, which has "destroyed" labour.

Finally, trade openness continues not to be significant while R&D is again negligibly driving carbon emissions. Kyoto-related evidence is confirmed as in par. *EKC specifications*.

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[18] The correlation between R&D/VA and VA/L is low: 0.0855.

Air pollutants

EKC specifications

For NOx, SOx and PM_{10}, which show sharp decreases since 1990, the EKC-related evidence suggests negative (for NOx and SOx) and non-linear cubic (for PM_{10}) relationships, which are worthy of careful investigation. Tables 4-6 present the main regressions in relation to comments in the text.

For PM_{10} the features of sector DF (coke, oil refinery, nuclear disposal) explain the final increasing part of the curve [19]. Re-coupling is possibly explained by initially increasing emissions and labour productivity trends, then (after 1997-1998) a decreasing emissions and productivity figure. Thus, it can be seen that the Italian situation is rather idiosyncratic and characterised by productivity slowdowns, especially during 2001-2006. In that period aggregate labour productivity decreased by 0.1% [20], the only case in the EU, and many industrial 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 re-coupling, may depend on a decrease in both emissions and productivity [21]. On the other hand, a slowdown may have negative implications for environmental efficiency, by lowering investments in more efficient technology, renewable and other energy saving and emissions-saving strategies that need initial investment and form the basis of complementarities rather than trade-offs between labour and environmental productivities. (Mazzanti and Zoboli, 2009) Further, the economic slowdown in association with higher than (historically) average oil prices may have created incentives for a re-balancing at the beginning of the century towards coal, as happened in the late seventies in most EU countries.

As stated above, both NOx and SOx show an absolute delinking. This evidence fits with the very sharp decrease in emissions observed over the last 20 years and can be also found in the statistically and economically very significant "Kyoto break" factor [22]. We can point out that, especially for SOx,

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[19] See fig. 5 for a graphic representation of the role of DF as outlier for PM_{10}.

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

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

[22] Very significant for all three 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.

the role played by income dynamics is less relevant for explaining environmental pressure dynamics relative to more exogenous factors, which are only partly captured here by the assessment of exogenous (policy) events. These may include the many regulatory interventions on air pollution by EU since the early 1980s (e.g. Directive 1980/779/EC substituted by the 1999/30/EC, 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.

Trade openness shows negative and significant coefficients, that are larger for SOx. If on the one hand the extra-EU_{15} related evidence suggests a stronger weight of the "pollution haven" factor relative to endowments, on the side of EU_{15} trade the motivations may include a number of perspectives. First, increasing trade openness (15.39% and 34.24% from 1995 to 2005 respectively for EU_{15} and extra-EU_{15}) is associated with a stricter integration in terms of environmental policy, which may explain the good and converging performance of eastern newcomers since the late 1990s. (Zurgavu et al., 2008) We can confirm that Italy is a "follower" and a convergent country in terms of environmental policy implementation in the EU context, thus this hypothesis has robust roots. Such convergence may also (have) occur(red) along pure market dynamics though technological spillovers and increasing technological and organisational environmental standards, in order to compete with European leaders. Second, along the path of increasing openness, intra-branch specialisations over time may be favouring more efficient technologies and production processes. This would support increasing Italian specialisation in more environmentally benign sectors and production processes. It is obvious that a structural decomposition analysis would be the best tool for assessing the relevance of these driving forces captured here, at a lower level of sector detail, using econometric techniques that result in more "average trends and statistical regularities".

Finally, it should be noted that SOx is the only case where R&D emerges as being associated with a statistically negative and economically significant coefficient[23].

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[23] This perhaps seems to conflict with what was said above about end of pipe exogenous effects associated with technological expenditures external to the firm (acquisition of equipment, thus not core R&D). Actually, in-house or external R&D may be better and primarily targeted towards externalities such as SOx, embodying some element of privateness in terms of rent appropriability, compared to pure public goods such as GHGs. We lack here a refined empirical definition of R&D typologies (firms specific, in-house, external, outsourcing R&D, and especially environmental and usual R&D) to attempt definitive statements. This is also scope for further research.

STIRPAT specifications

As far as the evidence of emissions vs labour productivity is concerned, the results again partly confirm the EKC analyses. Tables 4-6 sum up the main regressions with reference to the comments in the text. For NOx an N-shaped relationship emerges. The re-coupling is explained only by the behaviour of DF branch, as seen above for PM_{10} (see Fig. 4). For SOx we found an inverted-N shape, determined in its central section by the positive relationship of DG (chemicals, accounting for 3.92% of total SOx emissions in 2005) and E (energy production, electricity, water and gas, accounting for 31.27% of total SOx emissions in 2005) branches. For these branches the temporal reduction in emissions is completely determined by the "Kyoto structural break" while the economic driver play a secondary role in our opinion. We therefore draw attention to this evidence in the light of future policy action on specific industrial sectors. Finally, the evidence for PM_{10} is of a positive relationship that depends, on average, on the association between lowering emissions and decreasing productivity, a situation we here recall and which characterizes most sectors, this being especially relevant in the second part of the period or even since 1995 (e.g. DF).

The link between labour and emissions dynamics is again central in the STIRPAT model. For pollutants, the estimated coefficients for labour are all well above 1 (apart from SOx) and therefore suggest an emissions saving dynamic, in association with a decrease in industrial employment over the period for most sectors. Over time, then, the size of the emissions/labour ratio reduces. This links the analysis to the reasoning on capital/labour ratio dynamics over time as a consequence of labour saving, neutral or capital saving innovations. (Mazzanti and Zoboli, 2009) The evidence for Kyoto factors, trade openness and R&D are quite the same as for the EKC analysis.

CONCLUSIONS

This paper provides new empirical evidence on EKC for GHGs and air pollutants at sector level. The analysis is highly original since it exploits a very rich and long sector panel NAMEA dataset, merged with data on trade openness and R&D expenditures. Though the period of reference is a business-as-usual, no-policy time setting for GHGs in Italy, we test whether a structural break in the 1990-2005 series occurred around 1997, the "Kyoto threshold". The peculiar stagnation/reduction in labour productivity that has affected Italy since 2001, in some sectors in particular, is also an interesting economic phenomenon whose investigation allows us to analyse the extent to which a no-growth dynamic influences environmental performance.

The results show that, looking at sector evidence, both decoupling and also eventually re-coupling trends could emerge along the path of economic development. Both the way that the stagnation periods affect environmental performance and contingent sector specificity emerge as relevant explanations of the various U and N shapes. CO_2 seems still to be associated only with relative delinking and performance is not compliant with the Kyoto targets, which do not appear to have generated a structural break in the dynamics. SOx, NOx and PM_{10} present as expected decreasing patterns, though the shape of the income-environment relationship is affected by some outlying sectors with regard to joint emissions-productivity dynamics. Innovation and policy-related factors may be the main driving force behind observed reductions in SOx. On the other hand R&D intensity shows weak, if any, correlation to emissions in all other cases. This evidence is both scope for further research and a claim towards more intensive private investments in CSR/innovation strategies and public support for core (radical) innovation drivers, at least in the short term. Various explanations may exist: R&D content has so far not been specifically oriented to increasing environmental efficiency or producing impure public goods externalities; eventual environmentally-oriented expenditures may take time to impact environmental performance; in addition, a large part of environmental innovation in the period we observe has been of end-of-pipe nature rather than "integrated clean processes", which are strictly linked to R&D activities.

The analysis of trade expansion over the period validates the pollution haven hypothesis in some cases but also shows opposite evidence when EU_{15} trade only is considered. This may be due to technology spillovers and a positive "race to the top" rather than to the bottom among the EU_{15} trade partners.

EKC and IPAT-derived models provide similar conclusions overall. The emissions-labour elasticity estimated in the latter is generally different from 1, suggesting a scenario characterised by emissions-saving technological dynamics for pollutants and labour saving for CO_2.

The application of heterogeneous panel estimators is a direction for future applied research to assess the extent to which U and N shapes emerge from "average" trends. From a data construction point of view, future research should aim at using environmental R&D and innovation data at sector level or by merging micro-data on (environmental) innovation (e.g. CIS) and emissions sector data. A final and challenging research direction would be to set up trade factors in terms of inter-sector and intra-sector datasets, by exploiting I-O tables and NAMEA or other compatible sources related to trading partners.

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

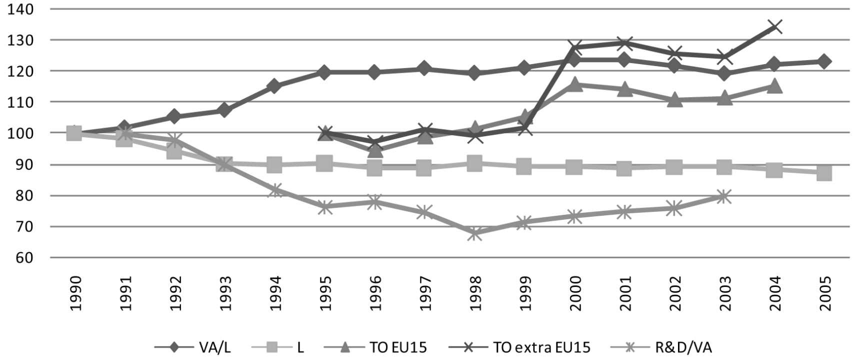

Fig. 2 – Emission/L trends (1990=100)

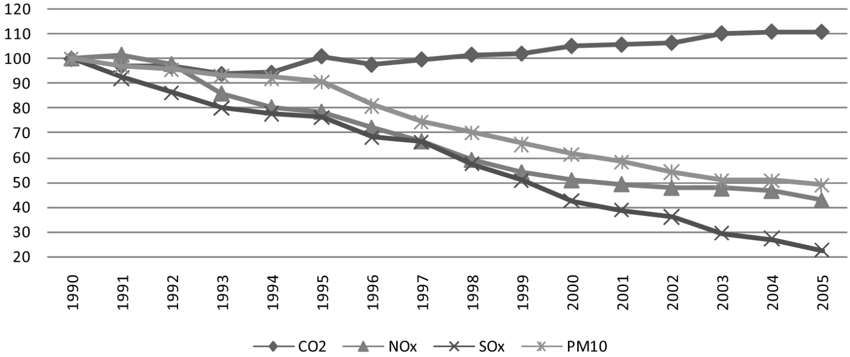

Fig. 3 – Emission trends (1990=100)

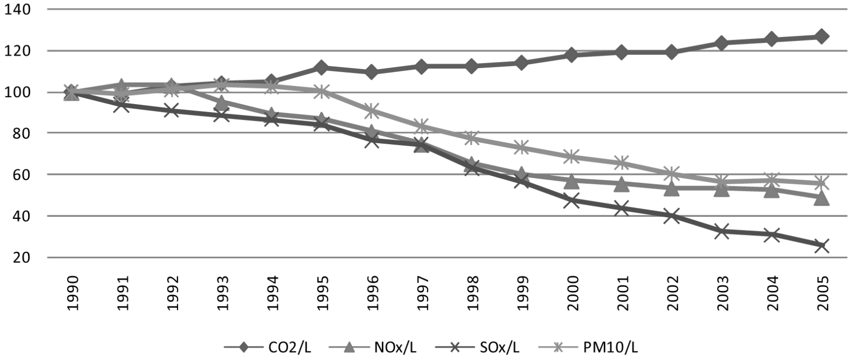

Fig. 4 – Outlier DF in STIRPAT estimations for NOx

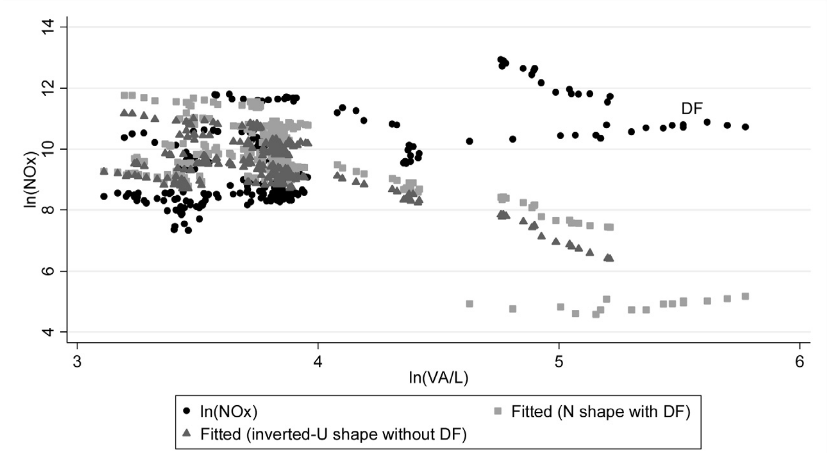

Fig. 5 – Outlier DF in EKC estimations for PM_{10}

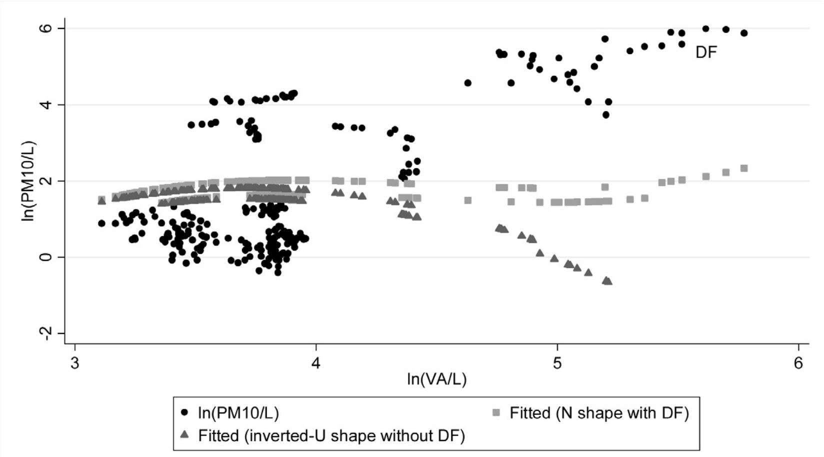

Table 1 – Nace branches classification

Nace (Sub-section)	**Sector Description**
DA	Food and beverages
DB	Textile
DC	Leather textile
DD	Wood
DE	Paper and cardboard
DF	Coke, oil refinery, nuclear disposal
DG	Chemical
DH	Plastic and rubber
DI	Non metallurgic minerals
DJ	Metallurgic
DK	Machinery
DL	Electronic and optical machinery
DM	Transport vehicles production
DN	Other manufacturing industries
E	Energy production (electricity, water, gas)

Table 2 – Descriptive statistics

VARIABLE	**MIN**	**MAX**	**MEAN (overall)**	**MEDIAN (overall)**
1990-2005				
VA/L	22.44 *(DD 1990)*	321.8 *(DF 1995)*	60.4614	44.9787
L	24 *(DF 2002; DF 2003)*	894 *(DB 1990)*	342.6458	269
1995-2004				
VA/L	25.53 *(DD 1995)*	321.8 *(DF 1995)*	61.9019	46.065
L	24 *(DF 2002; DF 2003)*	859 *(DJ 2003)*	336.8867	266.5
TO EU_{15}	0.0241 *(E 1999)*	4.8922 *(DF 2003)*	1.2204	0.8864
TO extra EU_{15}	0.0442 *(E 1997)*	12.796 *(DF 2002)*	1.2148	0.7538
1991-2003				
VA/L	23.76 *(DD 1991)*	321.8 *(DF 1995)*	61.4177	45.2194
L	24 *(DF 2002; DF 2003)*	884 *(DB 1991)*	341.7179	270
R&D/VA	0.0863 *(DE 1992)*	179.7654 *(DM 1993)*	22.3832	3.5698

Table 3 [24] – Estimation results for CO_2

	EKC Base	**EKC R&D**	**STIRPAT Base**	**STIRPAT R&D**
ln(VA/L)	1.2351***	1.3142**	0.2747***	0.28***
$ln(VA/L)^2$	-0.0894*	-0.0946*		
$ln(VA/L)^3$				
ln(L)			0.4702***	0.3581**
$ln(L)^2$				
$ln(TO_{EU15})$				
$ln(TO_{extraEU15})$				
ln(R&D/VA)		0.0314**		0.0331**
Kyoto	0.1059*** (111.17%)	0.0758*** (107.87%)	0.1068*** (111.27%)	0.0825*** (108.59%)
Constant	6.633***	6.3653***	11.9596***	12.5232***
R^2 *(overall)*	0.6517	0.5799	0.0093	0.0418
*N*T*	240	195	240	195
Period	1990-2005	1991-2003	1990-2005	1991-2003
Turning point(s) (VA/L)	995.9355	1035.681		
Turning point (L)				
Shape (VA/L)	Inverted U shape	Inverted U relationship	Linear	Linear

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[24] Notes (Tables 3 to 6): Coefficients are shown in cells: *10% significance, **5%, ***1%. For each column we present the best fitting specification (linear, quadratic, cubic) in terms of overall and coefficient significance. All specifications are estimated using FE model. Individual fixed effects coefficients are not shown for brevity. Below Kyoto coefficient, between brackets, average emissions in 1998-2005 given 1990-1997 average equal to 100% are shown. F test is the joint test of significance on all coefficients whereas F test fixed effect is the test of significance on individual fixed effects. TP both for VA/L (two for cubic and one for quadratic specifications) and L are shown: between brackets there is the percentile of each TP. Underlined TP are outside the range of the observations of VA/L or *L*

Table 4 – Estimation results for NOx

	EKC Base	**EKC TO_{UE15}**	**EKC $TO_{extraUE15}$**	**EKC R&D**	**STIRPAT Base**	**STIRPAT $TO_{extraUE15}$**	**STIRPAT R&D**
ln(VA/L)	-0.2353*			-0.4356***	17.5185***	2.0343*	20.5051***
$ln(VA/L)^2$					-4.1857***	-0.2136*	-5.0256***
$ln(VA/L)^3$					0.3198***		0.3875***
ln(L)					1.7012***	5.1037**	1.5873***
$ln(L)^2$						-0.345*	
$ln(TO_{EU15})$		-0.1842*					
$ln(TO_{extraEU15})$			-0.1402***			-0.3675***	
ln(R&D/VA)				0.0573**			0.0473*
Kyoto	-0.281*** (75.5%)	-0.1869*** (82.95%)	-0.1402*** (86.92%)	-0.2516*** (77.76%)	-0.2369*** (78.91%)	-0.1413*** (86.82%)	-0.2003*** (81.85%)
Constant	4.9698***	3.9319***	3.7893***	5.6613***	-23.4735***	-12.8072**	-25.7964
R^2 *(overall)*	0.2105	0.0962	0.0099	0.4508	0.0638	0.0104	0.1061
*N*T*	240	150	150	195	240	150	195
Period	1990-2005	1995-2004	1995-2004	1991-2003	1990-2005	1995-2004	1991-2003
Turning point(s) (VA/L)					32.5723*** *(20)* 188.9175*** *(96)*	116.9912** *(87)*	27.0493*** *(6)* 210.4844*** *(96)*
Turning point (L)						1631.075	
Shape (VA/L)	Linear	-	-	Linear	N shape	Inverted U shape	N shape

Table 5 – Estimation results for SOx

	EKC Base	**EKC TO_{UE15}**	**EKC $TO_{extraUE15}$**	**EKC R&D**	**STIRPAT Base**	**STIRPAT TO_{UE15}**	**STIRPAT $TO_{extraUE15}$**	**STIRPAT R&D**
ln(VA/L)	-0.4132**	-0.6327**	-0.5669**	-0.49**	-24.5418**	-53.5357***	-40.9568**	-0.7507***
$ln(VA/L)^2$					5.5087**	13.059***	10.1738***	
$ln(VA/L)^3$					-0.4052**	-1.0214***	-0.807***	
ln(L)					1.267***	1.5332***	1.0075*	
$ln(L)^2$								
$ln(TO_{EU15})$		-0.9637***				-1.1893***		
$ln(TO_{extraEU15})$			-0.9358***				-1.0842***	
ln(R&D/VA)				-0.1139***				-0.1199***
Kyoto	-1.0989*** (33.32%)	-0.8174*** (44.16%)	-0.7255*** (48.41%)	-0.9505*** (38.66%)	-1.0762*** (34.09%)	-0.8569*** (42.45%)	-0.7597*** (46.78%)	-0.9647*** (38.11%)
Constant	5.6662***	6.1581***	5.6025***	6.1292***	38.3794***	71.2995***	56.0784**	12.7666***
R^2 *(overall)*	0.005	0.0065	0.0167	0.0284	0.0164	0.1222	0.0662	0.0328
*N*T*	240	150	150	195	240	150	150	195
Period	1990-2005	1995-2004	1995-2004	1991-2003	1990-2005	1995-2004	1995-2004	1991-2003
Turning point(s) (VA/L)					51.5564*** *(79)* 167.4224*** *(94)*	30.8795*** *(9)* 162.9848*** *(94)*	28.2465*** *(2)* 158.1438*** *(93)*	
Turning point (L)								
Shape (VA/L)	Linear	Linear	Linear	Linear	Inverted N shape	Inverted N shape	Inverted N shape	Linear

Table 6 – Estimation results for PM_{10}

	EKC Base	**EKC TO_{UE15}**	**EKC $TO_{extraUE15}$**	**EKC R&D**	**STIRPAT Base**	**STIRPAT TO_{UE15}**	**STIRPAT $TO_{extraUE15}$**	**STIRPAT R&D**
ln(VA/L)	19.6917***			23.0763***	0.679***		0.3187*	19.0652**
$ln(VA/L)^2$	-4.5009***			-5.4313***				-4.4405**
$ln(VA/L)^3$	0.3379***			0.4138***				0.339**
ln(L)					9.4668***	9.6937***	11.4679***	5.7015***
$ln(L)^2$					-0.6537***	-0.6788***	-0.8452***	-0.3604**
$ln(TO_{EU15})$		-0.77***				-0.6694***		
$ln(TO_{extraEU15})$			-0.6756***				-0.521***	
ln(R&D/VA)				0.0772***				0.063**
Kyoto	-0.3736*** (68.83%)	-0.2269*** (79.7%)	-0.1674*** (84.58%)	-0.2688*** (76.43%)	-0.3383*** (71.29%)	-0.2153*** (80.63%)	-0.1755*** (83.91%)	-0.2624*** (76.92%)
Constant	-26.3633***	1.729***	1.5335***	-30.0582***	-27.2291***	-25.2118***	-31.2168***	-39.8468***
R^2 *(overall)*	0.0046	0.0957	0.0078	0.2382	0.014	0.0043	0.0108	0.0367
*N*T*	240	150	150	195	240	150	150	195
Period	1990-2005	1995-2004	1995-2004	1991-2003	1990-2005	1995-2004	1995-2004	1991-2003
Turning point(s) (VA/L)	49.6182*** *(76)* 144.7329*** *(91)*			37.784*** *(29)* 167.005*** *(94)*				44.8828*** *(47)* 138.017*** *(91)*
Turning point (L)					1396.108***	1261.817*	884.0189***	2721.959***
Shape (VA/L)	N shape			N shape	Linear		Linear	N shape