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# **Environmental Efficiency, Emission Trends and Labour Productivity: Trade-Off or Joint Dynamics? Empirical Evidence Using NAMEA Panel Data**

## **Summary**

The paper provides new empirical evidence on the relationship between environmental efficiency and labour productivity using industry level data. We first provide a critical and extensive discussion around the interconnected issues of environmental efficiency and performance, firm performances and labour productivity, and environmental and non-environmental innovation dynamics. The most recent literature dealing with environmental innovation, environmental regulations and economic performances is taken as reference. We then test a newly adapted EKC hypothesis, by verifying the correlation between the two trends of environmental efficiency (productivity, namely sector emission on added value) and labour productivity (added value on employees) over a dynamic path. We exploit official NAMEA data sources for Italy over 1990-2002 for 29 sectoral branches. The period is crucial since environmental issues and then environmental policies came into the arena, and a restructuring of the economy occurred. It is thus interesting to assess the extent to which capital investments for the economy as a whole are associated with a positive or negative correlation between environmental efficiency of productive branches and labour productivity, often claimed by mainstream theory dealing with innovation in environmental economics. We believe that on the basis of the theoretical and empirical analyses focusing on innovation paths, firm performances and environmental externalities, there are good reasons to expect a positive correlation between environmental and labour productivities, or in alternative terms a negative correlation between mission intensity of production and labour productivity. The tested hypothesis is crucial within the long standing discussion over the potential trade-off or complementarity between environmental and labour productivity, strictly associated with sectoral and national technological innovation paths. The main added value of the paper is the analysis of the aforementioned hypothesis by exploiting a panel data set based on official NAMEA sectoral disaggregated accounting data, providing both cross section heterogeneity and a sufficient time span. We find that for most emissions, if not all, a negative correlation emerges between labour productivity and environmental productivity. Though this trend appears driven by the macro sectors services, manufacturing and industry, this evidence is not homogenous across emissions. In some cases U-shapes arise, mainly for services, and the assessment of Turning Points is crucial. Manufacturing and industry, all in all, seem to have a stronger weight. Overall, then, labour productivity dynamics seem to be complementary to a decreasing emission intensity of productive processes. The extent to which this evidence derives from endogenous market forces, industrial restructuring and/or from policy effects is scope for further research. The relative role of manufacturing and services in explaining this pattern is also to be analysed in future empirical analyses. In addition, the role of capital stocks and trade openness are extensions which may add value to future analyses carried out on the same NAMEA dataset.

**Keywords:** Decoupling, NAMEA Emissions, Labour Productivity, Sectoral Added Value, Kuznets Curves, Environmental Efficiency

**JEL Classification:** C23, Q38, Q56

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## 1. Introduction

Indicators of ‘decoupling’ or ‘delinking’, that is improvements of environmental/resource indicators with respect to economic activity indicators, are increasingly used to evaluate progress in the use of natural and environmental resources. OECD is doing extensive work on decoupling indicators for reporting and policy evaluation purposes (OECD, 2002).

Various decoupling or resource efficiency indicators are included in the European Environment Agency’s state-of-the-environment reports (EEA, 2003c). A few European countries started to include delinking-oriented indicators in official analyses of environmental performance (DEFRA/DTI, 2003). Some countries are considering delinking-based targets for major environmental policies, and the US adopted an ‘emission-intensity’ target for their climate policy.

Delinking trends have been under scrutiny for decades for industrial materials and energy in advanced countries<sup>1</sup>. In the 1990s, research on delinking extended to air pollution and GHG emissions, also proposing ‘stylised facts’ on the relationship between pollution and economic growth named as ‘Environmental Kuznets Curve’ (EKC)<sup>2</sup>. The EKC hypothesis is the natural extension of delinking analysis. The hypothesis is in short that for many pollutants, inverted U-shaped relationships between per capita income and pollution are documented. The hypothesis does not originally stem from a theoretical model, but it has followed a conceptual intuition, though recent contributions have started showing the extent to which the Environmental Kuznets hypothesis may be included in formalised economic models.

The present paper builds upon the EKC background providing a different perspective. It tests an “adapted” EKC hypothesis, where the correlation between labour productivity (added value per employee<sup>3</sup>) and environmental efficiency (environmental indicators, here emissions, per unit of added value<sup>4</sup>) is the link under analysis<sup>5</sup>. It can be said that this test is one of the implicit tests that are carried out when verifying the relationship between the environmental indicator and the economic driver, since the dynamics of the two aforementioned “efficiency” is one of the core, if not primary, element behind the observed macro EKC trend. The role of technological innovation as latent factor behind the EKC hypothesis has often been raised by empirical and theoretical contributions. Technological (and organisational) innovations are then composed of “normal” innovations and environmentally oriented ones. It is worth studying the potential complementarities

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<sup>1</sup> For the extensive evidence until the early 1990s see Tilton (1988, 1991) on metals/materials, Martin (1990) on energy, and Zoboli (1995) for a selective review and discussion.

<sup>2</sup> Among the early works on pollution, see Holtz-Eakin and Selden (1992), Ten Kate (1993), Selden and Song (1994), Grossman and Krueger (1994). See also for a critical assessment of recent developments Dinda (2004), Stern (2004), Cole (2003), Mazzanti and Zoboli (2005) and Mazzanti, Montini and Zoboli (2006a,b).

<sup>3</sup> Full time equivalent jobs is the variable used by NAMEA.

<sup>4</sup> We define in this paper “environmental efficiency/productivity” the ratio of emissions on added value, which is often used in environmental accounting systems as it represents the intensity of emissions per unit of income. It is more an intensity indicator rather than a productivity or efficiency indicator. It is probably more intuitive since emissions are effectively a by product of economic growth, not an input (like labour), though theoretically they are nevertheless correlated with energy and other environmental inputs.

<sup>5</sup> For instance, Femia and Panfili (2005, p.59), stress that: “it is final energy consumption that activated the highest quantity of lead emissions per labour input unit, while it comes only third, after manufacturing and construction, in a ranking by intensity of lead emissions per unit of added value activated. These ratios express the trade-off embodied in the existing technologies between environmental targets on the one hand and economically and socially relevant variables on the other hand (at sectoral level)”. Thus, standard EKC and the present analysis on productivities may differ in outcomes.

over time; in other words whether normal innovations drive technological environmental dynamics or, avoiding causality links, whether a correlation between the two types of innovation exists.

Slightly different from the usual EKC framework, where the dependent variable is plausibly a (per capita) environmental indicator, we here specify a model wherein we maintain emission per sector added value as dependent variable. This is, to all effects, a proxy of environmental efficiency (environmental intensity of added value generated). The underlying assumption is that the core stream of productivity enhancement is the one linked to labour productivity, and that test is on whether environmental efficiency is positively or negatively correlated to the primary technologically driven dynamics, which in themselves possess various characteristics in terms of labour saving outcomes.

Our focus is predominantly macro, though intermediate between a macro country based analysis and an industry based investigation. The microeconomic level is also relevant from both a theoretical and an empirical level. With regard to the first point, we will below integrate macroeconomic and microeconomic theoretical elements in order to set a robust framework for the empirical assessment. Empirically speaking, though they would be highly crucial, micro firm-based analyses on environmental efficiency/productivity and labour productivity are prevented by the lack of available emission data at firm or establishment level. At firm level, it is currently only feasible to investigate relationships between environmental innovation and labour productivity, as demonstrated by the recent literature (Mazzanti and Zoboli, 2006, and sections below). Sector-based data like those provided by NAMEA are, in any case, a robust intermediate framework in between macroeconomic and microeconomic considerations.

It is worth noting in these introductory notes that recently the macroeconomic Keynesian model has been extended to environmental issues, attempting to include an environmental sustainable equilibrium, in addition to the goods and money market equilibrium. The adjusted IS LM framework, though, intrinsically short run oriented, bears some resemblance to the EKC arena. As economic activity exceeds some environmental equilibrium, policy actions and/or spontaneous market forces will combat pollution and possibly readjust the equilibrium. Heyes (2000), Lawn (2003) and Sim (2006) contribute to this evolution. The main interest to us is the assumption underlying the environmental schedule, which is downward sloping in the interest rate-income space following the hypothesis by which the environment intensity of economic activity is increasing in the cost of capital. This implies that lower interest rates and larger investments and capital stocks are associated with a lower relative environmental intensity. In addition, this signifies that the substitutability between capital and environmental services determines the slope of the schedule, which is flatter the higher the substitutability. Less inherent but worth mentioning, the macro framework including environmental equilibrium is interesting from the point of view of endogeneity of environmental quality and environmental policy. In the basic model, the IS LM adjustment to a full equilibrium is driven by exogenous policy movements by a rational social planner. More realistically and interestingly, this adjustment may be instead automatic and driven by market forces, in case it is assumed that (i) stricter policies raise prices and cause a readjustment to equilibrium through a monetary shrinking, (ii) the IS schedule depends on environmental quality (GDP, consumption and productivity may be negatively affected by lower environmental quality): IS shrinking could thus readjust the equilibrium following an environmental unsustainable balance.

Going directly to the focus of the paper, we here aim at testing the correlation between two different streams of productivity within industries. Given the relevancy of issues like: environmental innovations drivers, the relationships and complementarities/trade-offs between eco-innovations and normal innovations, the links between environmental performances and productivity trends, all those key points will be discussed in depth, grounding on the main recent and relevant contributions directly and indirectly addressing the network of the aforementioned relationships (in section 2).

The paper is structured as follows. The second section provides both a synthetic analysis of contributions which tackle the potential trade-off and complementarities between the two productivity dynamics. Our primary aim is a discussion revolving around the hypothesis of complementarity (correlation) or trade-off between environmental efficiency and labour productivity, for a vector of major emissions.

Section three will then present the dataset and the panel based regression analysis, highlighting the added value of our database with respect to the existing literature. Section four concludes with comments and hints for further research.

## **2. The dynamics of environmental efficiency and labour productivity in innovation processes**

### **2.1 A General overview on theoretical issues**

This section provides a synthetic analysis of theoretical and empirical issues which tackle the potential trade-off or complementarities between the two dynamics. The related literature usually originates within the discussion of the Porter hypothesis and within the framework of environmental regulations effects on firm performances. Given the central role played by innovation at firm and industry level, we briefly examine the extent to which empirical works focusing on the relationships between environmental performance, financial and productivity performance and innovation may provide useful hints to discuss the core hypothesis of the paper. We comment on both works relying on firm based data and industry based data; the firms based framework is perhaps less coherent to the present paper, nevertheless much of the empirical effort has been performed at that level. Many suggestions and hints regarding the correlation between diverse environmental and environmental innovations emerge from that field of study.

For a detailed critique of the “Porter” hypothesis (Porter and Van der Linde, 1995) we refer to Jaffe et al. (1996) and Mohr (2002)<sup>6</sup> who empirically and theoretically address the hypothesis that environmental regulation may benefit affected firms. Belse and Rennings (2001) also address the issue from the point of view of lead market creation in environmental fields, presenting two case studies on wind energy and car emission technology. Lead market may stem from pure endogenous market strategy or from policy related effects. Environmental regulations may along this line influence innovation and the market (rent) creation, either under a strong hypothesis (national policy alone may positively affect innovation) or under a lighter hypothesis (cross country homogeneously implemented policy affect innovation). The first hypothesis is stronger since it implies that regulations may affect innovation even if the comparative advantage in terms of regulation costs does not favour the national firm. In the long run, regulation costs are more than compensated by the benefits of innovation in

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<sup>6</sup> His model shows that endogenous technical change makes the idea feasible; however, a policy producing this outcome is not necessarily optimal for an extended social point of view.

terms of higher efficiency and/or higher added value, depending on the process/product content of such innovation. The focal point from a theoretical and empirical perspective is the extent to which innovation is arising from pure market strategies and/or from policy related effects. This key point leads the reasoning towards the policy impact assessment framework, which is currently crucial in the European policy debate (EEA, 2003a,b,c). On the one hand, innovation effects may underestimate the benefits of some policies in the ex ante perspective, if innovation dynamics are not taken fully into account, in their static (only efficiency) and above all dynamic features (Mazzanti and Zoboli, 2006). On the other hand, ex post analysis must assess the effective role of policies in shaping innovation dynamics; this evaluation issue is rather complex since it needs the setting up of BAU/counterfactual dynamic scenario, and cannot rely on experimental control groups (Mazzanti, Simeone and Zoboli, 2004). In this framework, one of the key issues is the competitive advantage of economic instruments with respect to innovation effects. Though theoretical contributions underline the higher potential of economic market based instruments, their role must be verified case by case. Even among market based instruments, in a dynamic scenario, where efficiency is not the only criterion, differences may arise.

Turning to the core of our reasoning, the complementarity/correlation<sup>7</sup> or, oppositely, a trade-off between labour productivity and environmental efficiency, is a hypothesis which implicitly emerges from the different levels of such streams of literature dealing with innovation, policy effects, firm performance under endogenous scenario and following exogenous impacts.

The levels are the following. First, the innovation impact of environmental policies, which may mitigate the net costs or even generate net benefits, from the firm/industry point of view. Secondly, the potential environmental innovation dynamics arising even without policy impacts from the endogenous market driven innovation dynamics of firms and industries. Third, the relationships, in the two situations listed (with and without policy), between “normal” innovation, primarily aimed at increasing labour and total factor productivity, and environmental innovation, defined as “new and modified processes, techniques, practices and products that reduce or avoid detrimental environmental impacts environmental innovation can be divided into technical or organizational measures” (Fronzel et al., 2005, p.3, for definition and discussions see also Mazzanti and Zoboli, 2006; Rennings et al., 2004; Horbach, 2006; Ziegler and Rennings, 2004<sup>8</sup>). A key question is whether it is possible to separate eco-innovation from other typologies of innovation. This is true for both technological (product/process) innovation and for organisational innovation, though the area of technological innovation is the one where often it is not easy to disentangle adoptions of incremental or radical innovations with respect to the aims of increasing standard firm productivity and environmental productivity. With or without policy (not only of environmental nature), it may be the case that cost-saving motivations, demand-related product market objectives could present a mix of different motivations, including environmental ones. All could be complementary for the general and final aim of enhancing firm productivity and, in a second consequential step, firm profitability<sup>9</sup>.

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<sup>7</sup> Here, we use the two terms somewhat synonymously, though a difference exists in technical terms between the two (Guidetti, Mancinelli and Mazzanti, 2006).

<sup>8</sup> See tab.1 in Rennings et al. (2003).

<sup>9</sup> See Konar and Cohen (2001) and other papers presented below in the survey, which deal with relationships between environmental and financial performance of firms. The focus is here more towards the potential complementarities of

The seminal paper by Jaffe et al (1995) is a starting point for a summary discussion based on theoretical and empirical considerations, around the issues of firm performances, environmental policy and environmental performances in terms, say, of emissions generated by firms/sectors. Though their reasoning, as with most of the literature, is focused on the link between environmental regulations and their effects on productivity growth, they also shed light on a wider framework. In other words, though environmental policies are increasingly an integrated part of our economies, and it is more and more difficult to disentangle policy led and endogenous performances, the conceptual issues raised can be applied whatever the environment of reference, with or without a (strong) policy regulatory framework.

They begin by commenting on the conventional wisdom, by which environmental regulations (like any other, of course) impose significant direct and indirect costs to firms and industries, with the primary effect of impacting negatively on many economic performances, and primarily (labour and total factor) productivity, which represents the heart of economic growth. The general picture is one where most pollutants show a strong decrease in levels over the recent decades, with total compliance costs rising over time. The issues are one with regard to the significant relationship between policies, compliance costs and (part of) those effects, the other, which is of higher interest to our paper, the role and the dynamics of productivity alongside the dynamic of environmental performance and policy strengthening. It is worth noting that these direct regulatory costs are unevenly spread across industries, with cost percentage in terms of turnover going from 0.15 to 1.80%<sup>10</sup>. Thus effects should be expected to be quite heterogeneous from industry to industry, even within manufacturing<sup>11</sup>. Though useful, survey based data can provide a partial view on some sectors and case studies. An analysis which is based on sectoral heterogeneity is more fruitful and could provide, compared to specific industry-based works, some hints on a general equilibrium perspective which implicitly incorporates inter industry interactions and cumulative effects of investment dynamics.

On the benefit side, some claim that environmental policies and, in general, environmental oriented strategies may be associated with private benefits with the great bulk of such benefits<sup>12</sup> being due to innovation effects. These effects on the process and product sides act as drivers of higher productivity and/or larger market demand (Kemp, 1997). This hypothesis, which takes different gradual forms from “hard” (private costs are in the end lower than private benefits, even excluding social benefits) to light assumptions (net costs remain positive on average with some sectors turning out winners and other losers in the “environmental” oriented

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innovation streams with respect to firm performance. Complementarity with regard to environmental innovations are analysed in Mazzanti and Zoboli (2006) and Frondel et al. (2005), Rennings et al (2003).

<sup>10</sup> Employment effects are not directly attributable to costs of benefits sides; nevertheless they represent a key issue. They could be also unevenly distributed, with strong negative effects of environmental strategies/policies for industries intense in low skilled works and, oppositely, potential positive effects on other industries. Rennings et al (2001, 1999) for example show, as presented below, that environmental innovation adoption tends to be linked to a skill bias. Employment effects are in any case only one element in the analysis of relative productivity performances.

<sup>11</sup> Manufacturing has been privileged in this field, given sectors are more exposed to international competitiveness and usually are affected by more stringent environmental policies, even if there is room for added value for analysis in the service sector as well.

<sup>12</sup> Jaffe et al. (1995, p.139) call these negative costs (“productivity impacts of a cleaner environment”), in a broad sense, including feedback effects on the environmental quality on labour productivity, and “potential innovation stimulating effects of regulation”.

economy), is linked to the well-known setting of the Porter hypothesis<sup>13</sup>. It also has connections with an evolutionary perspective of industrial dynamics, where the balance between entry and exit of firms is the main driver of development. Along those lines, environmental pressures could create an increasing wedge between innovative firms (sectors) and less innovative firms which could in the end disappear. The former may present higher performance on an all-inclusive innovative ground, positively integrating and correlating environmental and non-environmental dynamics (Saviotti and Pyka, 2004).

Provided that the proper way for assessing trends and impacts is an analysis of all diverse social and private benefits and costs related to environmental dynamics, it follows that it is quite hard to disentangle policy-led and autonomous business strategy effects. This is increasingly true as environmental policy develops. Jaffe at al sharply claim that the first problem is the determination of an appropriate baseline<sup>14</sup>. In other words, firms might engage in some or a great deal of pollution control “to limit liability, stay in good terms with communities, maintain good environmental image, etc..”. They ask whether such expenditures should be included or excluded from the baseline scenario. Secondly, besides end of pipe technologies, firms usually have strong difficulties in accounting specific capital and current environmental expenditures. If on the one hand this may derive from accounting technical problems, it could also be due, as discussed later on, to the entangled nature of many environmental and “normal” innovations<sup>15</sup>.

Let us turn back to the endogenous/exogenous comparison, which is crucial for the assessment of the correlation between labour productivity and environmental performances (eventually mediated by policies in the exogenous framework, and, in both cases, by innovation). If firms are operating efficiently, it is true that exogenous impact tends to decrease measured productivity, if not anticipated and already “internalised” in innovation dynamics, since capital, labour and energy are diverted to the production of this new good. Then, new practices may be more or less efficient than the old ones, and new investments may crowd out other investments<sup>16</sup>. All in all, the key question revolves around the maximising efficiency properties of the endogenous scenario and on the possibility that firms may undertake some environmental strategies in the endogenous path.

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<sup>13</sup> The light hypothesis is that environmental service sectors may benefit, together with sectors receiving environmental spillovers. A hard hypothesis is that the economy as a whole or most sectors may benefit given induced innovation and long run net private benefits stemming from regulations. In a general term, environmental costs/strategies, of any root, impel firms to reconsider their production processes, discover innovative ways to reduce energy use and pollution, thus potentially decreasing input use and increasing output/added value levels. Regulations and a new minded environmental management may increase the resources devoted to research, even if firms were choosing the private optimal level, if the social rate of return to research is higher than the private one, as empirical works seem to outline. Even with regard to R&D, it is relevant to analyse its external and internal causes and the complementarity between various output innovation drivers, including, amongst the others, R&D (Mazzanti and Zoboli, 2006).

<sup>14</sup> Millock and Nauges (2006) evaluate the effect of the French tax on air pollution using data from 1990 to 1999 for a plant level dataset. They find a negative, although small, effect of the tax on main examined emissions, using a two stage model where an innovation function is first estimated and then used as explanatory variable in a second stage, where emissions are the focus variables. Along the same line, we may refer to contributions by De Vries and Whitagen (2005) and Popp and Johnstone (2006), which analyse the effects of policy efforts, proxied by various variables concerning environmental stringency, and firm based factors on environmental innovation, both at the input and at the output side.

<sup>15</sup> Although trivial, we have definitions of innovation and environmental innovation, but in practice it is often not easy to separate them.

<sup>16</sup> As noted by Kemp and Volpi (2006), we should be concerned not only by trade-offs and complementarities between environmental and non-environmental innovation, but also by the fact that a diffusion of a clean technology could affect the diffusion of another clean technology; given sunk costs and uncertainty, the winning technology is not by definition the most efficient (Mazzanti and Zoboli, 2006).



Within this discussion of costs and benefits of environmental industrial strategies, the role of market demand creation is relevant, as we said, together with the entangled element of process and product innovation. The role of demand for innovation dynamics has been quite neglected recently<sup>17</sup>. We may observe that environmental strategies, even when led by regulations, may be a case where technology oriented and demand oriented innovation dynamics coexist with equal weights. Environmental costs borne by firms are aimed at increasing efficiency in static terms; nevertheless, in an evolutionary setting, they are associated with a situation wherein the presence of potential unmet demands spurs innovative firms. Environmental oriented new demands are a component of the qualitative (and structural) change of production along economic development (Saviotti and Pyka, 2004). Productivity growth in existing activities and generation of new demands and innovation spaces are in fact complementary sources of development, as variety growth (development of new sectors), and productivity growth in pre-existing sectors are complementary and not independent aspects of development. This is coherent with the fact that we expect innovative and high performing firms to be more successful in the environmental space. Innovative firms may perceive the “new (increasing) demands” arising from public and private spheres more than others. Sectoral heterogeneity is nonetheless relevant, probably more than dimension and performances.

Summing up, Jaffe et al provided useful and still-debated hints. Their main claim is that, if the strong version of the Porter hypothesis is (maybe) valid only for some specific niche sectors, then, on the other hand, the negative link between environmental costs and productivity is also not robust. The evidence, with regard to environmental performances and total and labour productivity, is ambiguous<sup>18</sup>. The value of studies on the dynamics of environmental performance, environmental expenditures and productivity is then high on those premises.

Collins and Harris (2005), add food for thought along similar lines (see also section 2.3.2 below)<sup>19</sup> recently discussing the dynamics of productive efficiency of firms according to the effect of pollution expenditures. On the one hand, as claimed by many authors, a polluter who spends on abatement activities is likely to reduce technical efficiency, since it is reducing investments in intermediate inputs and capital goods, other things being equal. Nevertheless, apart from the fact that the impact may be low or even negligible at the margin given the often limited proportion of resources potential “diverted” by regulations (Biondi and Zoboli, 2003), we may consider that (i) abatement technologies, which are environmental innovations, may be, to some extent, not strictly separated from the other technological dynamics, as often implied by mainstream works and by most

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<sup>17</sup> Demand dynamics have been less considered in both neoclassical theories, emphasising the role of exogenous technical change and technological endogenous spillovers, and evolutionary perspectives, which often narrates a supply side story. Schmookler’s (1966) seminal work claimed that demand conditions influence the desirability of innovations and the expected profitability and expansion of market demand represents a key stimulus (Pianta, 2001; 2005). Environmental pressures, though full of supply side technological elements, could be perceived as an uncertain framework of increasing and new demands.

<sup>18</sup> Some works are commented on even below in the short survey. In a nutshell, Gray and Shabdegian (1993) find some evidence in favour of negative productivity effects of abatement expenditures, of around 1.5% in elasticity terms. Haveman and Christiansen (1981) is a rare study focusing on labour rather than total productivity.

Added value measurement and data reliability is a key issue for giving robust results, even outside survey based environment. We here rely on official panel data provided by national NAMEA accounting system indicators and added value provided by Official Institute of Statistics.

<sup>19</sup> Their study would be included in research line (iii) below: they analyse the effect of abatement expenditures on productive efficiency concerning the chemical sector.

works studying regulatory impacts, and, correlated to the first point (ii) private and public external rents may be correlated as well. If this is true, we require other theoretical tools stemming from public economics and technological innovation fields in order to understand this more complex framework, wherein both technological elements and externalities associated with firms are characterised by complementary, opposed to substitution-based, relationships.

It also emerges that this reasoning, though mostly functional to the discussion of regulatory tools, defines less clear cut boundaries between what is referred to as optimal (maximising) behaviour without policy, and the above commented impact of policies. If complementarities happen to exist, we will see that the links between private and public elements lead to an endogenous firm strategy aimed at internalising a part of social cost following motivations related to costs saving, market based drivers and technological rents. Even at the private profit maximisation level, environmental issues are not excluded a priori by firms, but it could be that they are more integrated as expected in business strategies.

As far as the hypothesis tested in this paper is concerned, it is worth noting that relating productivity to abatement costs (environmental input) and productivity to pollution production (environmental output) is not the same thing. The above reasoning should suppose, for a full application to the analysis of two productivities, that there is a direct inverse correlation between abatement expenditures and pollution production. In average terms, higher pollution expenditures (controlling sector heterogeneity of course) should be associated with lower pollution levels; at the margin, more efficient and less polluting agents should/could invest in less incremental resources.

In connection to what we discussed regarding abatement expenditures and productivity, we also note that average and marginal stories may differ: in average terms, we expect that total or average expenditures on abatement are positively correlated to polluting reduction (which is a part of environmental efficiency); while at the margin more efficient firms may spend fewer resources on abatement<sup>20</sup>. Since our reasoning is based on macro evidence, this implies that the average related dynamic is more coherent, though creating pollution and spending on pollution are not necessarily the same<sup>21</sup>.

Consequently, though most contributions focus, given the interest in policy effects, on the relationship between productivity and abatement efforts (supposing abatement as a proxy of policy impact, which is partially true in our theoretical setting), our focus is on the correlation between labour productivity and environmental performance, deriving from abatement expenditures, of an end of pipe and/or process integrated nature. In average terms, it is plausible to assume a positive link between abatement and pollution reduction, thus what said above can be almost totally translated into our framework. It remains that an analysis of the dynamics of the two potentially entangled productivities (pollution/added value and added value/employees) implies a more complex framework, where environmental performances, added value and employment dynamics have to be examined in an integrated manner.

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<sup>20</sup> The marginal abatement cost is nevertheless higher, other things being equal, for more efficient firms.

<sup>21</sup> A focus on expenditures rather than pollution indicators may be misleading if inefficient firms had both higher pollution costs and lower productivity. A spurious correlation could emerge between the two, depending on the of the firm's core of efficiency.

As noted by the authors, the relationship between pollution (and then environmental efficiency or environmental performance) and productivity is in fact another piece of the puzzle and can take various forms. Filtered by the abatement/environmental regulation argument, the nexus between labour productivity and environmental productivity strongly depends on the existing interconnection at technological level and at the level of the specific externalities addressed. It concerns the manifold “employment, added value and environmental impact” of environmental and non-environmental technology. In a micro setting, therefore, we should analyse the drivers of both environmental and environmental techno-organisational innovations, looking at eventual trade-offs and complementarities, then consequently assess the impact of both in terms of employment, added value and environmental impact.

Summing up, we argue that the links are, in effect, at least two: (i) one between labour and environmental productivity, in the endogenous scenario, where abatement and environmental innovation may exist at some level, following some profit and other (maximisation) strategies<sup>22</sup>, (ii) one between abatement and labour productivity, where abatement derives from a policy exogenous effort aimed at internalising the “externalities” which are not addressed spontaneously by firms. In this case, abatement is exogenous and can modify the maximisation strategies, with likely negative impact, at the margin, on productivity, for the reasons expressed above. The third nexus is the one connecting abatement to pollution levels, that we specified above on average and marginal terms.

Having said this, our hypothesis of positive correlation between labour and environmental productivity is consistent with the so called “asymmetric case” (Collins and Harris, 2005, p.750), where it is assumed that as efficiency is higher in technical terms, the firm produces more good output and less bad output. The “symmetric” case instead assumes that higher efficiency produces more good and bad outputs. In other words, they claim that the symmetric setting is also consistent with a framework, opposed to the production function approach, wherein firms are allowed to simultaneously increase good and lower bad outputs<sup>23</sup>.

The next sections provide the reader with a further discussion, emerging from theoretical reasoning (2.2) and on many recent empirical research results (2.3), of our tested hypothesis that environmental efficiency and labour productivity *may be* positively correlated over a dynamic path. Economic theory, mainly on less mainstream fields, and empirical analysis, give hints in favour of such a hypothesis. Empirical evidence is nevertheless needed, and probably, but quite obviously, varies according to factors like sector, time period, and country. Our panel data analysis is a robust starting point for what we believe is a fruitful stream of theoretical and applied research.

## 2.2 The double externality issue, innovation complementarities and impure public goods

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<sup>22</sup> The level of environmental investment could be zero in the extreme scenario of pure public good externalities and completely disentangled nature of the private and public elements of technology and externalities, calling back the double externality metaphor.

<sup>23</sup> Collins and Harris note that higher labour productivity may arise either because of the use of a superior technological setting, which may have benign environmental effects, or because of a higher capital stock. In the first case, firms with superior technology and with the same capital per worker experience higher productivity. In the second case productivity is higher but capital per worker is also higher; capital productivity may be lower. Capital intensity is another element linked to the dynamics of labour and environmental productivity which we do not extensively address here.

Following the above discussion, two correlated issues may be addressed here in order to set out more specifically the theoretical underpinnings of our hypothesis. First, with regard to environmental innovations, in addition to the higher or lower effect of diverse instruments and policies on innovation<sup>24</sup>, one may ask which type of environmental innovation can be derived, whether of process type (end of pipe or integrated) and/or product type. The answer remains strongly based on empirical evidence, which is quite scarce on this ground (see below 2.3.1).

Secondly, in this frame we face two potential externalities. In fact, environmental innovations 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 (Jaffe et al., 2005). Thus, subsidies and taxes may be applied in an integrated manner tackling two different objectives; complementarity between different instruments could also emerge, though trade-offs are also possible and cannot be underestimated.

The double externality issue and the typology of (environmental) innovation dynamics are entangled factors which constitute the heart of our framework (Vollebergh and Kemfert, 2005).

Different levels of reasoning arise. First, as said, innovation aimed at reducing environmental impact may also spur positive innovation spillovers. This is a first element of complementarity that in our framework may explain why and by which dynamics environmental efficiency is not de-linked from labour productivity dynamics as implied in most mainstream literature.

Then, and most critical, environmental innovations may not be specifically disentangled from other types of innovation. It is true that “normal” innovation may harm or improve the environment. In the first case a trade-off exists, in the second case the boundary between environmental and non-environmental technological dynamics are more ambiguous. This means that even in the BAU scenario, that is without policy intervention, the adoption of innovation may give rise to energy or environmental saving, aimed at minimising costs and/or increasing rents. Policy could then enhance the innovation effort beyond the market driven reason. One additional hypothesis which further works may test is whether incremental innovations are more likely to be associated with complementarities between environmental and non-environmental techno-organisational dynamics, whereas radical innovations, at least in the field of environmental dynamics, need to be supported by policies or by the expectations of future policy introduction or higher stringency<sup>25</sup>.

The picture becomes rather complex, both within the firm and outside the firm (exogenous drivers of innovation), with respect to a world where inputs, innovations, and policies are separated and links/relationships are then more clearly defined. The arising network of complementarities and trade-off designs a system where at both firm strategy level and policy level is crucial to understand the full matrix of relationships associated with innovation dynamics, performances and policies.

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<sup>24</sup> An issue clearly outside our scope is the relative effects on static efficiency and innovation dynamics of CAC and market based instruments. In the empirical world, each single instruments of a policy may have different effects (Hahn and Stavins, 1991; Requate, 2005; Requate and Unhold, 2004).

<sup>25</sup> Under the framework of analysis developed here, it is relevant to study the complementarity and the trade-off between policies: not only for environmental policies, but also between different environmental and non-environmental aimed policies (see Mohnen and Roller, 2005 for an analysis on the complementarity concerning obstacles to innovation), in the fields of innovation, and in the labour market field.

Environmental and non-environmental innovation may then be correlated with their adoption and in their motivations. Theoretical underpinnings may be many.

One reason is that the production of some “environmental goods” is associated with rents which are appropriable, at least partially, by firms; they are private goods, or the private part of an impure public good, possessing other pure public features. Many environmental innovations combine an environmental benefit with a benefit for the company or user (Hemmelkamp, 1997). As an example, see the differences between water use and air emissions, mainly CO<sub>2</sub>; in the first case, it is more likely that firms autonomously adopt saving strategies, whether or not a policy is present, in the second case it is less likely given the prevalent public good nature (for the firm) of emissions, which are more difficult to internalise or reuse in production processes<sup>26</sup>. This difference between natural resources and correlated externality leads to various gaps between environmentally accounted and standard productivity. Bruvoll et al. (2003) analyse the extent to which environmental policies affect firm productivity, interestingly focusing on potential differences between standard measures of productivity and measures accounting for “environmental” inputs and outputs. Such differences may go in both positive and negative directions. They find, for example, that environmental inclusive productivity is higher than usual measure when examining water resources, while the opposite emerges when focusing on air emissions, primarily CO<sub>2</sub>, which are tackled with more difficulty by firms having less private elements and more public good features. Thus, the innovation potential of policies, and the associated innovative endogenous strategy of firms regarding environmental resources depend on the features of environmental goods. Those goods may be characterised by private appropriable rents and by public elements. This complementarity in production, that is a technologically-based positive correlation between the private fully appropriable and the public good factor, is potentially linked to both/either relationships existing at the level of externalities or product features (e.g. local/global emissions, private or public product/process innovation features; see Kotchen, 2005; Rubbelke, 2003; Loschel and Rubbelke, 2005)<sup>27</sup> and at the level of technologies (e.g. relationships existing among apparently separated technological dynamics: environmental/non-environmental; technological/organisational). Technology and externalities are in any case theoretically interrelated environments; and non convexities in production could be an important element for the joint production of private and public values, depending on fixed costs and technological constraints (Papandreou, 2000; Boscolo and Vincent, 2003).

The mix and the correlation of the two levels, within an impure public good framework, are crucial, for assessing the environmental strategy of firms, the role of policies<sup>28</sup>.

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<sup>26</sup> The issue is also linked to compliant and non compliant environmental investments. As reported by da Motta (2005), theory would suggest that profit maximization leads agents to equalize compliance and non-compliance costs at the margin. Compliance costs require firms to adjust to the norms and policy requirements, while non-compliance costs regard market incentives like increased competitiveness (in green oriented market) and reduced operational costs, among the others.

<sup>27</sup> Regarding impure public goods (Cornes and Sandler, 1997), see some papers which have exploited and analysed the concept within the social capital (SC) literature dealing with the relationship between SC and innovation and performance of firms and local systems (Cainelli et al., 2005; Mancinelli and Mazzanti, 2004; Glaeser et al., 2002; Durlauf, 2004).

<sup>28</sup> Ziegler and Rennings (2004) comment on this issue. The double externality problem may increase the importance of the regulatory framework since the addition of two externalities, one positive and one negative, may lead to suboptimal investments in environmental innovations, which are supposed to be appropriable with difficulty. A correlation between private and public elements may mitigate this outcome, favouring investments on innovation even without policy interventions. It remains true that the core point of the reasoning is the private incentive of firms to invest, which depends,

The survey presented below will highlight from an empirical point of view that environmental innovations, though reducing external costs, may be motivated by the usual business goals such as reducing costs or enhancing product quality (Rennings et al, 2001).

This “complementarity” between usual techno organisational innovation and environmental innovation may be opposed to the “substitution hypothesis” which often derives from a usual neoclassic reasoning, which tends to hide the possibility that firms adopt environmental innovation in a non policy scenario. Then, when policies are introduced, a trade-off between environmental and non-environmental firm divisions is hypothesised: in fact, if the firm is optimizing resource allocation in production (before environmental regulations), any additional abatement cost or innovation cost deriving from policy enforcement leads, at least in the short run, to an equal reduction in productivity, since labour and capital inputs are re-allocated from “usual” production output to “environmental output” (pollution reduction).

Summing up, the impure public good feature plays its role in two directions, which show themselves to be interrelated. It also provides new insights and concreteness to the cited “double externality” metaphor, basing itself on innovation and environmental externalities.

On the one hand, we may say that environmental pressure by firms may be diversified into more private (local) effects, or effects which are easily internalised and tackled even in the non policy scenario. Some technological processes may be adopted to reduce the environmental impact as well as the non-policy scenario since (i) some environmental pressures possess more private oriented features, appropriable by firms; (ii) some non-environmental technological dynamics are interrelated to non-environmental technologies, and are potentially fully-integrated in production processes. Both points present the case that firm strategies could be characterised by a higher than expected integration, over the dynamic technological path, by usual and environmentally oriented innovation. The private/public nature of environmental externalities and related environmental innovation, from the firm perspective, plays a crucial role. Then, the role of policies emerges as one that corrects for externalities, which are not “already” tackled by the endogenous technological dynamics developed by firms and industries, which is driven by demand, cost, product value added and other market based motivations. We may say that complementarity between private and public elements of environmental goods, and complementarity between different technologies, help the achievement of a sustainable path. What is crucial is that, in this context of correlated production of private and public elements, in order to stimulate the virtuous cycle of private and public goods<sup>29</sup>, a market based threshold must be overcome (Cainelli et al., 2005, 2007).

A threshold, defined in terms of market opportunity costs (interest rate, product price expectations, market demand level, input prices, etc..) beyond which the private element (e.g. the “non-environmental innovation”) is produced, adopted or financed by R&D, and consequently leads to (some) production of environmental innovation. In a nutshell, then, environmental innovation can be either linked to fully appropriable rents or the public part of an impure public good, where fully private and public good oriented innovations are “technologically” positively correlated in production. In the latter case, incentives rely on the market. Public good under provision is mitigated or driven to nil.

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summing up, on the degree of appropriability of innovation rents. The lower this degree, the lower the chance of experiencing strong innovation dynamics in the endogenous scenario and the higher the necessity of policy factors.

<sup>29</sup> For firms, private appropriable rents and public external rents.

For completely public elements, policies then provide additional stimulus, both in a world where internal and external elements are fully separated for the firms, and in a world where they are somehow integrated. What changes is the evolution of environmental and non-environmental dynamics in the endogenous path.

We know that innovation is the key towards sustainable dynamics, from both a macro and a microeconomic perspective. Complementarities, when present, help, since they enhance the innovation content of the BAU scenario even without policy and regulatory efforts<sup>30</sup>. This is a key point which also emerges from the EKC literature, which is aimed at assessing the extent to which the endogenous path driven by growth only is coherent with the achievement of sustainability. Policies are necessary in any case to fully correct for external effects; the role of policy changes, since it has to be analysed in a world where it is more complex. On the one hand, then, policies are “favoured” by endogenous complementary dynamics, but nevertheless their role has become more specific and even more difficult to analyse. A framework characterised by an organisational system composed of technological separated components is more complex, and therefore, the effects of policies, though mitigated probably in their scope, are rather difficult to assess, given the interdependencies between positive and negative externalities, different negative externalities, and different environmental and non-environmental innovations aimed at enhancing firm efficiency and firm performances more generally.

What we underline is that the “pessimistic” view of a trade-off between environmental and non-environmental strategies of firms may be mitigated by a framework where provided complementarities exist along the discussed lines. Those complementarities, which concern at their heart different technological innovations (labour-oriented, environmentally-oriented), could explain (at least one piece of the puzzle) why increasing environmental efficiency is compatible with increasing labour productivity. A clearer-cut separation between private and public elements (rents) leads instead to a framework where substitution dynamics between different technological innovations are likely to be assumed. Our framework, given its macro nature, it is probably not the best level at which to study the full matrix of relationships associated with innovation dynamics, performances and policies. Our aim is primarily to focus the attention on the potential positive correlation between labour and environmental productivity, presenting some robust empirical evidence at industry level. We encourage empirical research on those lines at a deeper micro level to define more specifically the underpinnings of this relationship.

### **2.3 Eco-Innovations, business strategies and firm performances: a critical survey**

Here, we comment on the main recent empirical contributions dealing with the interconnected issues of environmental innovation, environmental policy and firm performances. These are relevant as a latent background set of (mainly) micro evidence on relationships between innovation, innovation drivers, environmental performances and firm performances, for our industry based level analysis. We subdivide the literature into three parts: investigations focusing on environmental innovation output and/or input drivers and those dealing with the impact of environmental innovation on employment (2.3.1). We also take a look at contributions focusing on both firm/sector environmental performance, and firm performances as dependent variables, since both analyses are useful to give a comprehensive outline of the entangled issues at stake (2.3.2).

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<sup>30</sup> Nevertheless, when you fully take into account an impure public good framework, the problem of defining the (market) based BAU with respect to the alternative (policy) scenario is more difficult. Market based drivers may stimulate, as discussed, some provision of public goods which is correlated to the production of private appropriable rents.

### **2.3.1 Eco-Innovation, innovation drivers, and employment effects**

In order to begin the short survey, we pick up a seminal work by Jaffe and Palmer (1997), who study environmental innovation by defining R&D and patents as dependent variables, at industry level. In a panel framework, they find that lagged abatement costs lead to higher R&D expenditures. They conclude that “data at the industry level are mixed with regard to the hypothesis that increased stringency of environmental regulations spurs increased innovative activity by firms”. No statistically significant relationships between regulations and innovative output are found.

Brunnermeier and Cohen (2003) employ panel data on manufacturing industries to provide new evidence on the determinants of environmental innovation. They measure innovation by the number of patents (waste treatment and containment, recycling and reusing, acid rain prevention, waste disposal, alternative energy sources, air pollution, water pollution) and they found, by exploiting a simple reduced, form that it responded to increases in abatement expenditures, while monitoring and enforcement activities associated with regulations did not impact innovative strategies.

Popp (2002) tests the “induced innovation hypothesis” (changes in relative factor prices should lead to innovations that reduce the need of the relatively expensive factor) at industry level using a 24 year-long panel (1970-94) where the dependent variable is the number of patents granted with regard to environmental innovation (supply and demand oriented technologies). Energy prices are the primary explanatory variable. Statistical units are 11 classified technology groups. Popp finds that both energy prices and the quality of existing knowledge exert a significant positive effect on induced innovation. It is worth noting that the author stresses that using patent data as a measure of research output poses several complications. Some industries widely exploit patents, while in others secrecy is a more important tool of intellectual assets protection. As a result the correlation between R&D and patents vary across industries. Those works represent typical examples of US oriented analysis, focused on patents as innovation proxies, and on abatement measures as policy proxy, and with empirical studies usually relying more on industry data rather than firm level data.

In the European setting, evidence on environmental innovation is recently provided by Frondel et al. (2005), who exploit OECD survey data for Germany at firm level (manufacturing industry), in order to investigate whether environmental auditing schemes (voluntary management-oriented organizational innovation) and pollution abatement innovation are correlated. The main conclusions are that the enhancement of corporate image is a potential force behind the adoption of EMS, while policy inputs do not seem to affect this organizational innovation. In addition, the influence of public authorities and the strictness of environmental policy seem to trigger abatement while EMS and other policy instruments do not.

Horbach (2006) exploits a two-year panel (2001, 2004), considering firms belonging to the “environmental sector” (firms offering goods or services related to the reduction of environmental impacts), then subdividing between innovative and non innovative firms (product innovation). A large vector of explanatory factors is tested, ranging from firm strategy to policy related factors, using both a probit binary model, where the dependent dummy is environmental innovation/other innovations (only restricted to innovators), and a MNL model, where three categories (environmental innovators, innovators, no innovators) are specified. Results show R&D, environmental regulation, EMS and general organizational changes trigger innovation. The author also



argues that evidence is in favour of the hypothesis that general and environmental innovative firms in the past were more likely to innovate in the present. This hypothesis and results are worth noting for this paper since they support the claim for complementarities between environmental and non-environmental innovation. One flaw of the study (and of other EU based studies later presented is that most drivers are discrete, mainly dummies).

Mazzanti and Zoboli (2005, 2006) present evidence for the manufacturing sector, focusing on the drivers of different adoptions of energy, emission and waste related innovations. They also analyse the effects of an extended set of drivers (environmental R&D, policy induced costs, EMS, industrial relations, other innovations) on innovation<sup>31</sup>, and they assess the degree of correlation between output innovation and between the most relevant innovation inputs that arise, such as R&D, induced cost and EMS. Strong evidence of complementarities at the level of innovation output, with regard to diverse environmental innovations, is found, while complementarities at input level are less strong<sup>32</sup>.

Rennings - Ziegler - Ankele - Hoffmann - Nill (2003) also provide evidence on Germany, focusing deeply on auditing schemes like EMAS and correlated environmental organisational innovations. They use a sample of eco innovative firms adopting EMS. This is, to some extent, a weakness since it prevents a general analysis with non EMS firms<sup>33</sup>. The main hypothesis they test is the influence of the «maturity» of EMAS (depending on the age and revalidation of EMAS and other elements) on environmental process, product and organisational innovation indexes. They find that EMAS has a positive effect on all three forms of environmental innovation at firm level, with a key role played by the R&D department. Firms achieving significant learning success with EMAS also show better economic performances. A positive correlation between different environmental innovations and also firm performance emerges

Other works are correlated with the two aforementioned papers, which we briefly sum up in order to describe the evolution of European studies. Together, they provide interesting cumulative evidence, using Germany, European and OECD data for some countries.

Related to the work previously mentioned, two other papers deal with the correlation between EMS and technological innovation. Ziegler and Rennings (2004) analyse the hypothesis that EMS and other environmental

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<sup>31</sup> Hansen - Sondergard - Meredith (2001) present an analysis of case studies regarding environmental innovations in small and medium sized enterprises, for five European countries. The study reveals a great variety in factors driving the process: character of environmental innovation, regulatory setting, firm strategic orientation, network relations, and sectoral influence. Innovative capability emerges as the result of the interplay between different driving forces. Very recent evidence on the variety of factors affecting environmental innovations, is provided by Gonzalez (2005) and Doonan - Lanoie - Laplante (2005), who examine pulp and paper industries. Da Motta (2005) shows evidence for a developing country, focusing on Brazilian manufacturing firms. Environmental performance, measured by the number of environmental control practices, is influenced by structural features of the firm and by community based and market based incentives. Cost inputs and subsidy are also found to be relevant, suggesting a flexible and differentiated approach to policy. Many of these factors may be complementary to each other or linked by trade-offs.

<sup>32</sup> With regard to environmental innovation determinants, the literature, at both firm and industry level, has mainly focused on single separated determinant of innovation. Some recent papers, among others (see below) Mazzanti and Zoboli (2006), Rennings et al. (2003, 2001), Frondel et al., (2005) also analyse potential complementarities. Florida et al. (2001) analyse the relationship between organizational resources/organizational innovativeness and EMS schemes, exploiting firm-level data, finding a positive correlation. Organizational factors may thus play a role in the adoption of green designs. In our case, EMS strategies are not correlated either to any of organizational innovative practices or to process/product innovations. When including all certification activities (ISO and EMS), correlations are moderately significant with TQM and process/product innovations.

<sup>33</sup> Regarding a US study, Florida - Atlas - Cline (2001) show that 24% of manufacturing firms with more than 50 employees adopt EMS schemes.

organisational innovations correlate<sup>34</sup> with process/product technological innovations, exploiting a sample of German manufacturing firms (2003 survey on firms)<sup>35</sup>. While R&D is positively related to both product and process environmental innovation, they find weak evidence in favour of the correlation between EMS and innovation. This, added to the more recent analyses commented on above, creates an ambiguous picture: some positive correlation is found, but not in all case studies<sup>36</sup>. Instead, this study shows that product designs and life cycle analyses are correlated positively with all forms of technological environmental innovation. Summing up, though evidence does not always robustly showing a positive correlation, there is certainly not a trade-off between technological and organisational environmental innovations; if not correlated, they may impact separately on the environmental and general performance of firms. As found by other studies, past firm performances do not seem to explain environmental strategies; thus there seems to be some correlation within the innovation arena, between different environmental innovations and also between different innovation dynamics, while financial performance remains detached from innovation dynamics, which are more inherent to productivity trends of firms and industries.

Rehfeld, Rennings and Ziegler (2004) mainly test the correlation between EMS, policy stringency and R&S (covariates) and product environmental innovation, exploiting the same dataset as above. Descriptively speaking, they find a high correlation between past and present innovation adoptions for both process and product. In the field of environmental innovations, confirming OECD datasets, process innovation are largely predominant<sup>37</sup>. They present a slightly different result, since in this case, but only in the MNL model, EMS results in being correlated with product innovations. There is some evidence, then, of a higher correlation between EMS and product innovation compared to process innovation. The opposite may be true for life cycle assessment, here not relevant as an explanatory factor of product innovation; thus there are some hints in favour of a higher role of LCA regarding process based environmental dynamics. A subjective measure of policy stringency, as well as R&D, results as positively related to innovation. R&D generally emerges as a significant input for output innovations<sup>38</sup>.

Frondel et al. (2004) instead focus attention on technological process innovation, and use a MNL model to test whether end of pipe measures or integrated cleaner production processes are driven by different factors. They

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<sup>34</sup> Throughout the paper we use the term correlation since, given the nature of survey data, most studies cannot present, if not by exploiting lagged variables, evidence on effective causality links, which are, in any case, difficult to define at conceptual level. We thus use the term correlation when presenting results concerning relationships between different innovations. The links between innovation, performances and policy factors are instead *more clearly* definable in terms of causality, provided panel data or lagged variables are exploitable.

<sup>35</sup> We note that, as in most studies of this literature, variables on innovations are forcedly subjective. Firms state their innovative adoptions and investments.

<sup>36</sup> Florida - Atlas - Cline (2001) analyse the relationship between organizational resources/organizational innovativeness and EMS schemes, exploiting firm-level data, finding a positive correlation. Organizational factors may thus play a role in the adoption of green designs. In our case, EMS strategies are not correlated either to any of organizational innovative practices or to process/product innovations. When including all certification activities (ISO and EMS), correlations are moderately significant with TQM and process/product innovations. For a US analysis on EMS effects on environmental performances see also Khanna and Anton (2002).

<sup>37</sup> Frondel - Horbach - Rennings (2004) consider a sample of 899 German manufacturing firms, finding that half of the firms have undertaken significant technical measures to reduce their environmental impact. Among those, largely predominant (90%) is the occurrence of process rather than product innovations. With regard to process innovations, the shares of structural changes and end of pipe technology are 56% and 42% respectively.

<sup>38</sup> Though there would be the need to distinguish, if possible, between general and environmental R&D. The division is usually not revealed by surveys and it is also difficult from the point of view of firms.

use an OECD survey-based dataset for seven countries on manufacturing firms. They exploit a large set of drivers, ranging from internal firm-based strategies to external policy variables. The main results are that policy stringency is more relevant for end of pipe innovations, while “market forces” like R&D, environmental accounting systems and audits, and cost saving motivations are more relevant for cleaner technologies.

They do not find any difference with regard to the drivers of product and process technological innovations; they claim that this is in line with the overlapping characterisation of the two technological options, when we look at the EC definition of product innovation that for specific products includes process changes from the cradle to the grave.

Summing up the recent evidence on the determinants of environmental innovation, we first notice that, given the survey-based nature of data, mainly in the European environment, different studies may present incommensurable results since they elicit core variables regarding innovation dynamics and policies by exploiting heterogeneous definitions. All in all, in any case, it seems that, though empirical research in the field, at least at micro level, has large space for further improvements and added value explorations, some common evidence arises. First, environmental innovations at the technological level seem to be related to each other; there may be a cluster of eco-innovative firms, quite separate from other firms. Secondly, environmental organisational innovations results in being positively correlated to technological innovations, though this may depend on which specification of organisational and technological innovation we use. Then, there is some evidence of correlation between eco and non eco-innovation; results are nevertheless scarcer with respect to this, and further research is needed on this additional high value point. R&D always plays a role, as well as policy impacts. Another added value research stream regards policy evaluation and the definition of homogenous and a comparable policy drivers, even at the level of subjective stated variables.

There is another line of research which is ancillary to the level of innovation determinants and is somehow relevant for our present paper. The hypothesis of this specific line revolves around the employment impact of environmental innovation at firm and industry level, this differentiating between direct impacts at firm level and more general equilibrium impacts for the industry or the economy as a whole. We refer to papers like Rennings and Zwick (2001), Rennings et al. (2001), Pfeiffer and Rennings (1999). What is relevant to our paper is the hypothesis, commented on in these works, that increasing environmental efficiency by environmental innovations strengthens competitiveness and the firm performance, with or even without a policy stimulus. An ancillary hypothesis is that eco efficiency investments require a higher amount of labour. The hypotheses are that on the one hand product innovation spurs employment since it creates new demand, while process innovations decrease employment since it is usually labour saving. Some employment compensation may occur by means of indirect price/market driven effects. For a general analysis on innovative factors and innovative motivations impacting employment see Pianta (2000)<sup>39</sup>. It is worth stressing that the process is a two stage one: first the firm decides whether or to invest in innovation, and then optimises the volume of labour following the innovation

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<sup>39</sup> See also Antonucci and Pianta (2002) for a treatment of employment effects of process and product “normal” innovations. As far as EU is concerned, they observe that process innovation has a negative impact while product innovation has positive effects, as well as sectoral demand expansion. They attribute weaker employment performance to the lower EU intensity in product innovations.

process (Rennings et al., 2001). See Pfeiffer and Rennings for a synthetic summary of direct and indirect, positive and negative effects of different eco-innovations on employment.

The first paper is based on a sample of eco-innovative firms for 5 EU countries, belonging to the manufacturing and service sector. It is worth noting that this is a rare study where some evidence concerning eco-innovations in the service sector is provided, being the evidence for manufacturing totally predominant. The authors, by using probit and MNL models (the dependent variable is discrete: increase, decrease or unchanged employment), the authors analyse the extent to which categories of eco innovation and eco-innovation goals (cost reduction, increase in market share, environmental motivation) affect employment, controlling for other drivers. Descriptively speaking, it is shown that most firms do not change employment as a consequence of innovation, but this may be due to the limited period of observation of the survey. Econometric results show that eco-innovation typologies do not influence the quantity of employment, apart from some effects registered for product innovations, though, as expected (Caroli and van Reenen, 2003), innovations seem to lead to a skill bias effect. Environmentally oriented innovation is skill biased following this evidence. Then, end of pipe innovations are related to a higher probability of job losses, while recycling innovations with a positive probability. As expected, while cost reduction motivations are associated with employment reductions, environmental specific goals are less likely to be associated with job losses. Other drivers like market share motivations of innovations or policy stringency are associated with more ambiguous outcomes in the MNL model.

The second paper exploits an EU-based survey in order to investigate the diversified employment effects. The dependent variable is again a discrete employment reaction variable. 88% of firms stated that eco innovations do not lead to specific related employment changes (differentiating between total and environmentally related effects), 9% affirm they increase employment, and only 3% state a decrease. Focusing on eco innovators only, conclusions are that process and product innovations tend to increase the probability of a higher labour stock, while, within process innovations, end of pipe technologies tend to present a negative effect. The skill bias is confirmed. On a rather descriptive basis, Pfeiffer and Rennings show that the positive, negative or stable effect of eco innovations on employment is possibly heterogeneous by type of innovations. As examples, the fields where the increase is observed to be higher are end of pipe emission control, waste disposal, process and product integrated innovations. Stability in any case prevails as already seen.

We note that employment impacts examined by the studies we have commented on, do not, as such, shed light on the more relevant labour productivity impact of innovation and specifically environmental innovation<sup>40</sup>. The core research question should be if, and by which mechanisms, environmental innovations positively impact on firm productivity, investigating the potentially correlated dynamics concerning different innovations, as presented and discussed in the papers above. The different hypothesis outlined above for the links between innovations, employment and, we stress, added value, might be the basis for reasoning around the (more) relevant relationship, over a dynamic scenario, between environmental efficiency and labour productivity. The role of eco-innovations and usual innovations lies, composed of different explanations and dynamics, behind the

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<sup>40</sup> Rennings et al (2001, p.4) in fact state: “environmentally friendly innovation does not necessarily increase the productivity of a firm, however. They may even reduce productivity and require increasing labour inputs per unit because they are often not motivated by cost reduction or increasing sales (both potential positive drivers of productivity), but by compliance with environmental regulations (Cleff and Rennings, 1999) and therefore the net effect is unclear”.

stage of this core relationship. One shortcoming of the survey data of the aforementioned paper is the intrinsic limited period of observation on which survey studies rely.

The analysis of productivity and performance impacts of environmental factors has been predominantly developed within the (US) literature on the effects of regulations on firm and industry performances which is briefly commented on below. Less attention has been paid to the specific effects of environmental innovations or environmental strategies in general with respect to firm performances. There is, along this line, a fruitful stream of research both for the manufacturing and the service sector (Cainelli et al., 2007).

### **2.3.2 Environmental performance, firm performance and policy**

With regard to models linking environmental performances to economic and policy drivers, let us begin with a recent paper by Cole et al. (2004), who exploit UK industry data for industry specific pollution emissions over 1990-2000 merged with industry (i.e. average firm size) and regional characteristics. They provide evidence on the forces lying behind pollution intensity at regional level, also taking into account the impact of local policies. They point attention to the observed heterogeneity in emission reduction across different pollutants, probably due to the presence of relevant industry specific determinants of pollution intensity. Quantitative analysis shows that pollution intensity is a positive function of energy use, and physical and human capital intensity, while the relation is negative with size, productivity and expenditures on capital and R&D. Results show that both policy drivers and firm endogenous characteristics are crucial in explaining the trend of pollution intensity in industry: certain influences on pollution are therefore beyond the (direct) control of (environmental) policymakers.

Foulon et al. (2002) instead use a specific case study (a small panel dataset for Canadian pulp and paper mills: 1987-1996, 15 plants) to investigate the effect of different policy efforts (Regulation, traditional enforcement (fines and penalties), and emerging public disclosure actions) on pollution intensity. They conclude that environmental performance was significantly affected by the tightening up of standards in 1990. Information strategies as public disclosure cannot replace traditional enforcement practices in the area of environmental policy. The two forms are thus complements, where the marginal impact of non traditional regulatory effort has to be further investigated. In the same sector, see the interesting work by Bruvold et al. (2003), who analyse the extent to which environmental policies affect firm productivity, interestingly focusing on potential differences between standard measures of productivity and measures accounting for “environmental” inputs and outputs. Differences may go in both positive and negative directions.

Finally, as far as contributions analysing the impact of environmental (policy) drivers on performances are concerned (see above 2.1 and 2.2), an interesting paper by Konar and Cohen (2001) investigates the effect on firm market performance (S&P market value for 321 US corporates) of tangible and intangible assets, including, among potential explanatory factors, two environmentally performance-related elements, the aggregated pounds of toxic chemicals emitted per dollar revenue and the number of environmental lawsuits pending against the firm. The authors present regressions both for a usual Tobin's q proxy of market value and for a proxy of intangible asset of the firm. The main contribution is to include “environmental performance” as explanatory variables in estimating intangible assets. Empirical results show that both variables of environmental performance are associated with negative and robust impacts. Cohen et al. (1997) also analyse the relationship

between environmental and financial performances. On the one hand, environmental performance and the associated regulatory pressure is costly, on the other hand a firm that is efficient in controlling pollution is likely to be efficient also at production. Moreover, a firm that does well financially can afford to spend more on cleaner technologies. Authors construct two industry balanced portfolios using 500 S&P Corporate firms, to compare both accounting and market returns of the high polluter to the low polluter portfolio. Overall, they find no penalty for investing in a “green” portfolio, or even a positive return from green investing. The fact that greener firms are doing as well or better than polluters may indicate that more efficient production processes also pollute less: a sort of complementarity may exist between overall production and environmental efficiency. On the other hand, greener firms may exploit better past performances in profits and productivity: this fact would identify a virtuous cycle for some and a vicious one for others. If we refer to our concern, a widening gap could characterise the future dynamics of local industrial areas. This gap is between innovatively-evolving agents, which attempt to increase the added value of production by integrated innovative strategies and more stagnant firms, responding to the challenge of international competition mainly by means of defensive behaviour. Gray and Shabdegian (1995) instead use total factor productivity and growth rates for plants in paper (101 units), oil (101) and steel (51) industries over 1979-1990 as performance indicators. They test the impact of environmental regulations and pollution abatement expenditures. They find that \$1 greater abatement costs are associated with \$1.74 in lower productivity for paper mills, \$1.35 for oil firms and \$3.28 for steel mills. Those are variations across plants in productivity levels. Instead, when analysing variation over time or growth rates, the relationship between abatement costs and productivity, as well as the impact of other regulatory measures, is statistically insignificant. The evidence on the “Porter hypothesis” is thus ambiguous: regulations do not increase long run firm performances, in this case productivity levels, but on the other hand a negative undermining effect is present only cross-sectionally<sup>41</sup>.

Greenstone (2001) estimates the effects of environmental regulations (Clean air act) on industrial activity, using data for 1.75 million plant observations that comprise the 1967-87 US censuses of manufacturers. In addition, a longitudinal regulation dataset allows for the identification of cross sectional variation in these regulations across counties, as well as changes in counties’ pollutant specific regulatory status over time. The regulation file is merged with the aforementioned plant observations. Evidence is based on a comprehensive panel dataset tested by specifying various specifications. It shows that environmental regulations retard industrial activity. Environmental regulations have negatively affected the growth in terms of employment, output and capital shipments for more polluting plants (sectors). The author stresses that “regardless of whether these policies pass or fail a cost-benefit test, this paper’s findings undermine the contention that environmental regulations are costless or even beneficial for the regulated”.

Gray (2004) also provides evidence on whether the various Clean air act amendments have caused the sharp decline in dioxide concentrations, finding a generally weak impact of the policy on the 80% SO<sub>2</sub> decline.

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<sup>41</sup> Gray and Shabdegian (2003) further analyse the link between productivity and abatement costs, testing whether the impact varies by plant vintage and technology. A dataset of 116 individual pulp and paper mills over 1979-90 is studied; evidence shows that plants with lower productivity also experience higher abatement costs: vintage does not affect the relationship, while technology does. The negative relationship is significant only for integrated mills, opposed to non pulping paper making mills, in the key technological distinction proposed by authors for the sector.

Summing up, the empirical evidence, though rapidly developing, is in any case too scarce and patchy to provide a micro based empirical foundation to our macroeconomic evidence. It nevertheless seems that firms may complementarily invest in different technological dynamics, given the high interrelation between human capital and techno organizational innovation, and the entangled nature of various technological aims (labour-oriented, environmentally-oriented, etc..). This is with regard to firm performance objectives, revolving round the pivotal role of firm productivity, which also depends on the (efficient and effective in terms of added value creation) use of environmental inputs and output (Bruvoll et al., 2003).

Those complementarities and correlations may emerge and be found in all the diverse directions highlighted above: the analysis of innovation determinants, where environmental and non-environmental firm strategies may arise as key explanatory factor; the analysis of productivity / performance effects of innovation, where both environmental and non-environmental drivers may play a role. The role of (environmental) policies, though not only these, then adds to this picture a potential driver, which could intervene, affecting the way technological and production processes develop in a more or less integrated way.

Following the theoretical and empirical discussion presented above, we move on to testing the aforementioned hypothesis. We provide evidence on the relationship between labour productivity and environmental efficiency exploiting sectoral data (aggregated industry level). This is a first attempt to highlight and test the hypothesis of correlation, opposite to the trade-off, between the two “productivity streams” with regard to labour and environmental goods (emissions in this case). It is, then, a stimulus for further efforts at the level of empirical analysis, in order to provide the microeconomic basis which could explain the positive or negative correlation between labour and environmental productivity and the associated technological innovation.

### **3. Environmental efficiency and labour productivity: evidence from NAMEA accounts 1990-2002**

#### **3.1 Database and context**

The source mainly used for the sectors-pollutants dataset implementation is the National Accounts Matrix including Environmental Accounts (NAMEA) recently published by ISTAT. The first NAMEA, referring to 1990 data, was published in ISTAT (2001) and then in the following years several other NAMEA were published up to the year 2002. Nine air pollutants<sup>42</sup> are considered by NAMEA data and they refer to emissions from several production activities that we have recoded by using 29 economic activities (2 in the agricultural sector, 18 in the industrial sector, 9 in the service sector). Other data about the national added value and the units of labour (full time equivalent jobs) are included in the NAMEA.

On the basis of the described dataset, we aim to analyse at industry level the relationship between environmental efficiency and labour productivity. Our time span, ranging from 1990 to 2002, allows robust evidence on the dynamic relationship between the two productivity elements. The panel nature of data allows an investigation which exploits both sectoral and time series heterogeneity, tackling the unobserved effect issue. A novelty is that

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<sup>42</sup> The NAMEA pollutants considered in this paper are: Carbon dioxide (CO<sub>2</sub>), Nitrous oxide (N<sub>2</sub>O), Methane (CH<sub>4</sub>), Nitrogen oxides (NO<sub>x</sub>), Sulphur oxides (SO<sub>x</sub>), Ammonia nitrogen (NH<sub>3</sub>), Non methane volatile organic compounds (NMVOC), Carbon monoxide (CO) and Particulates matter (PM10).

we exploit NAMEA accounting, which is a panel of observations for emissions produced by productive branches of the economy (Femia and Panfili, 2005)<sup>43</sup>. We use a disaggregation based on 29 sectoral branches<sup>44</sup>.

### 3.2 The main hypothesis

We test whether environmental efficiency (productivity), deriving from innovation and structural changes leading to emission reduction is, following technology based and externality based complementarities relationships<sup>45</sup>, positively associated with labour productivity. The hypothesis we implicitly assume in the empirical model is that environmental impacts (environmental efficiency) are dependent on the core dynamics of innovation, aimed at enhancing labour productivity<sup>46</sup>. In other words, we (i) explicitly test whether the two productivities are disentangled (no significant correlation), positively related (correlation/complementarity between the two), or negatively correlated (substitution trade-off framework); (ii) implicitly verify whether the associated innovation dynamics aimed at increasing firm productivities act separately or jointly.

It is primarily a test on the relationship between labour and “environmental” productivity, and efficiency in production. It is more or less indirectly a test on the correlation between environmental-oriented and other innovation dynamics. Summarising what has been commented on above, it remains possible that on the other hand, environmental innovations may displace other technological innovations, for various financial and policy related reasons (Jaffe et al., 2005). We believe that productivity and innovation dynamics are more integrated than expected. We also refer to the most recent literature on innovation and performances, that emphasises that the mere introduction of (single) new technologies, instead of bundles of organisational innovation and new human resource management practices, does not seem to always support better performances (Black and Lynch, 2004; Ichniowski et al., 1997; Huselid and Becker, 1997; Laursen and Foss, 2003). Bundles of high-performance and innovation practices are needed. Referring to section 2.3.1, we remark that such complementarities, with respect to firm performance, may regard both environmental and non-environmental technological innovations and different environmental innovations, of technological (process / product) and organisational type.

The empirical model is:

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<sup>43</sup> The authors present some descriptive analytical applications of NAMEA exploiting 1995 and 2000 data. They calculate and analyse environmental or eco-efficiency ratios, which we may also intend as environmental productivity of industries and the economy as a whole.

<sup>44</sup> We are prevented from using the full breakdown into 50 branches, given that accounts were not available for all such branches in the first years. Data losses would have been too large. We decided to structure the panel by assigning equal weights to temporal and cross section heterogeneity, instead of biasing towards the latter with a shorter but larger dataset.

<sup>45</sup> Complementarity may be opposed to the “substitution hypothesis” which derives from a usual neoclassic reasoning. In fact, if the firm is optimizing resource allocation in production before environmental regulations, any additional abatement cost or innovation cost deriving from policy enforcement leads, at least in the short run, to an equal reduction in productivity, since labour and capital inputs are re-allocated from “usual” production output to “environmental output” (pollution reduction).

<sup>46</sup> Using a shift share analysis (Dunn, 1960; Esteban, 2000) it would be possible to disentangle an environmental productivity trend in three components: allocative, differential productivity and structural industry mix. Since data regarding at least two areas is needed for carrying out the analysis, this study is prevented here given the time series availability of only national data. We suggest as future empirical effort a shift share analysis focusing on NAMEA indicators for different EU countries. A decomposition analysis on air emission trends is presented by Bruvoll and Medin (2003).



$$(1) \quad \log(\text{Emission/Added value}) = \beta_{0i} + \alpha_t + \beta_1 \log(\text{Added value/employees})_{it} + [\beta_2 \log(\text{Added value/employees})^2_{it}] + e_{it}$$

where the first two terms are intercept parameters, which vary across sectors and years. Different polynomial specifications are tested, starting from linear then testing squared specifications. We note that this is not a pure EKC framework. We first test the linear form to assess the significance of the correlation and its eventual positive or negative nature. In case of positive significance of the correlation (with a more or less proportional increase of emissions on added value), the inverted U-shape is tested in order to verify whether the assessed link between productivity has a non linear dynamic pattern which may refer to EKC frameworks. Turning points are not estimated in any case. It is worth noting that since we specify the ratio of emissions on added value as an index of environmental efficiency, an inverted U-shape would tell us that environmental efficiency is increasing (the ratio decreasing) as labour productivity increases, in association with a negative elasticity between the two productivities. The cases are in fact (at least) three: the correlation is negative in the linear form (our hypothesis is proved), the correlation is positive (it may have an elasticity higher than one or lower than one), the correlation is linearly positive but associated with a non linear shape (EKC-like or exponentially increased). The core test is on a correlation link between two productivity indicators. Provided the strong interrelationship between the two trends over a dynamic scenario, we do not intend to endow our statistical results with a strong causality “aspect”, though, if we wanted to define a causation link in the empirical model, we may quite plausibly assume that is labour productivity that leads the technological path, eventually affecting, in a secondary step, the dynamic of environmental innovation. The panel nature of data, presenting high sector based and time series heterogeneity, makes our investigation robust.

Thus, for each combination of the dependent and independent variable listed above, different specifications are estimated, including: the linear regressors only (delinking baseline case), linear and squared terms (EKC most usual case)<sup>47</sup>. Given the panel data framework, the relative fit of fixed effect and random effect models is compared by the Hausman statistic. A LSDV model with time period effects is additionally estimated. Finally, we test the presence of first order serial correlation<sup>48</sup>, AR (1), to verify whether this correction significantly affects estimates.

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<sup>47</sup> The baseline test is carried out on a linear specification, which is efficient for this purpose. In case it is significant, we introduce the squared term, though we are aware that an eventual EKC shape has different implications and interpretations, since we correlate two productivities and not an environmental pressure index with a proxy of economic growth.

<sup>48</sup> Following the procedure in Wooldridge (2002, p.176), which tests serial first order correlation by a t test on the coefficient of the lagged fitted residual term in a regression which sees the fitted residual in time T and the vector of explanatory factors as independent variables. Lagged residuals are significant in both FEM and REM models, thus the correction model, which does not consider time T for estimation, is indicated. As noted by Wooldridge (2002, p.176), one interpretation of serial correlation in the errors of a panel data model is that the error in each time period contains a time constant omitted factor. Serial correlation may be verified by a test on the residuals (Wooldridge, 2002, p.176). If the null hypothesis of no correlation is not rejected, the model is definable as dynamically complete in the conditional mean. In any case, the loss of efficiency in presence of correlation, in models that involve relatively slowly changing variables, like consumption and output, is not so severe (Greene, 1997, p.589-590). In addition, we note that if the stationarity assumption holds, autocorrelation fades over time, but correlation has to be dealt with since it may cause more or less severe losses of efficiency.

We recall that the corrected correlation model reduces the number of observations since it is based on T-1 periods, unlike the time period effect model.

### 3.3 Empirical evidence

#### 3.3.1 Evidence for the Italian Economy

In order to test the relationship between an index of environmental productivity (emissions produced per unit of added value) and an index of labour productivity (added value per unit of labour), we use the aforementioned adapted EKC empirical model<sup>49</sup>.

This outcome is of high importance in understanding the evolution of our economic system and for informing policy makers on potential complementarity links.

We may first summarise (tab.2) outcomes as follows, starting from logarithmic specifications. For CO<sub>2</sub>, N<sub>2</sub>O<sup>50</sup>, CH<sub>4</sub>, NO<sub>x</sub>, NMVOC and CO the sign of the linear correlation term is negative. NH<sub>3</sub> instead presents a positive sign on the linear correlation. Nevertheless, the LSDV model with time periods is definitely preferred following the LR test, and it presents a significant negative coefficient on VA/N, as long as the serial correlation specification. Then, even for NH<sub>3</sub> a sign of negative correlation emerges in the end.

The observed negative “elasticity” is lower than one for CO<sub>2</sub>, N<sub>2</sub>O, NO<sub>x</sub>, CH<sub>4</sub>, and PM<sub>10</sub> and higher than one for SO<sub>x</sub>, (NH<sub>3</sub><sup>51</sup>), NMVOC, CO.

SO<sub>x</sub> outcomes are less homogeneous with respect to pollutants we previously commented on. VA/N presents a negative sign, though the statistical analysis is less conclusive since also a squared specification with signs – and + is quite significant. Though the negative coefficient prevails in absolute level terms, the trend is driven in the end by the positive squared element (the estimated TP is outside the VA range, that is, currently the relationship is characterised by a negative link). Then, the elasticity is lowered by the use of a time period effects FEM model. Overall, the evidence is more in favour of a negative correlation with a higher than one elasticity, though results are somewhat less clear than for other emissions.

We note that the inclusion of the squared element drives additional relevant information for CO<sub>2</sub>, CH<sub>4</sub>, SO<sub>x</sub>, NH<sub>3</sub>, and PM<sub>10</sub>. An EKC pattern is in fact associated with CO<sub>2</sub> which here presents both the linear and squared specifications significant under a statistical perspective. This does not change the interpretation on the link between CO<sub>2</sub> efficiency and labour productivity. NH<sub>3</sub> also presents quite robust inverted U-shape evidence. In both cases, nevertheless, logarithmic and non logarithmic specifications present reversed signs on the coefficients. For CH<sub>4</sub>, NMVOC and PM<sub>10</sub> the inverted U-shape evidence is instead weaker and the linear regression, is all in all, preferred as specification. SO<sub>x</sub> was commented on above<sup>52</sup>.

Empirical EKC contributions exploit both logarithmic and non-logarithmic analyses. Though logarithmic specifications are statistically preferred, we also carry out, as a test, non-logarithmic specifications, which do not

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<sup>49</sup> We are aware that being outside a classical Kuznets framework, the choice of the dependent variable is debatable: we maintain as dependent variable the environmental indicator, supposing the primary factor of strategic investment by firm and industries still remains the labour productivity trend.

<sup>50</sup> In this case only non logarithmic specifications are significant (see tab.2 and below).

<sup>51</sup> For NH<sub>3</sub> and also NMVOC evidence concerning elasticity is not conclusive. The base specification shows a negative elasticity higher than one, other specifications a negative elasticity lower than one.

<sup>52</sup> Some inconsistency between logarithmic and normal specifications also arises. To sum up, the empirical model seems to perform better with linear regressions. Some inverted U shape evidence is worth noting, but it is more ambiguous. We argue that this was partially expected since the aim is not one of assessing an EKC pattern but of assessing the statistical robustness of the correlation between emissions/added value and labour productivity. The assessment of the inverted U shape was a secondary objective of the analysis.

affect and change results. In others, they present a lower overall significance, proving the expected higher performance of logarithmic ones. We note that with regard to  $\text{NH}_3$  the non logarithmic analysis presents a significant negative correlation, with an elasticity of 0.21 estimated at mean values. Elasticities calculated in non logarithmic setting at mean values are generally lower (tab.2). Apart from  $\text{CO}_2$ ,  $\text{SO}_x$  and  $\text{PM}_{10}$ , point elasticities estimated at mean values are lower than one<sup>53</sup>.

Only in one case ( $\text{CO}_2$ ), the signs are reversed with respect to previous analysis, but looking at the levels of coefficients, we note that the negative sign, though on the linear factor, is strongly higher, thus prevailing on the positive squared term for current labour productivity levels.

It is worth noting as a final point that we tested the influence of sector dynamics by including dummies for services, manufacturing and other industries; those variables result as generally not significant. Thus, though the dataset shrinks, we provide as final exercise specific evidence for three sub samples of NAMEA.

### **3.3.2 Evidence on disaggregated samples: industry, manufacturing and services.**

Further empirical analysis may be focused on the disentangled manufacturing, industry and services branches. The benefit is that we may observe potential differentiated dynamics concerning the productivities link, between services and manufacturing. The current cost we face is a lower statistical robustness due to data losses when splitting the full dataset. This analysis may be oriented towards testing diverse hypotheses; we here aim at providing preliminary evidence on what the drivers of the assessed relationship between productivities are at sectoral level. For example, using NAMEA data, Femia and Panfili (2005) observe that service activities are more efficient from an environmental point of view, though not as much as one could have expected. The reason may be that those sectors induce matter transformation even if the “product” is not directly material.

Tab.3 presents a summary of outcomes with synthetic comments of sector and aggregate trends. We may classify evidence in three levels. As far as  $\text{CO}_2$ ,  $\text{CH}_4$ ,  $\text{NO}_x$ ,  $\text{CO}$ ,  $\text{NMVOC}$  and  $\text{PM}_{10}$  are concerned, the negative correlation (with some signs of inverted U-shape emerging at aggregate level) appears driven by all three macro sectors showing negative relationships between the two productivities. For  $\text{NO}_x$  and  $\text{CO}$  evidence is less clear cut. The main sector driver seems to be industry and manufacturing, even if for  $\text{CO}$  industry seems to play the leading role (that is, the three sectors added to manufacturing in the industry analysis: energy, construction, material extraction). Services present a negative correlation, but a U-shape emerges, though with TP currently outside the observed range.

Then,  $\text{N}_2\text{O}$  and  $\text{NH}_3$  (agriculture though relevant is not estimated due to data paucity) show signals of inverted U-shape with TP within the range. In the former case, manufacturing/industry show the most significant and similar EKC like trend. For  $\text{NH}_3$ , as in the aggregate, the picture is more ambiguous: linear forms confirm a positive sign on the relationship, though inverted U evidence arises adding the quadratic term, with TP outside the range only for services. Finally,  $\text{SO}_x$  confirms to act as an outlier in statistical terms. Though a negative correlation is assessed in the linear form, the quadratic term is positive and leads to TP which are outside the range only for services. The trend is then possibly characterised by a positive correlation between productivities

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<sup>53</sup> For  $\text{PM}_{10}$  and even  $\text{CO}$  the elasticity is statistically not different from unity.

both at aggregate and sectoral level; but if the aggregate level presented TP well outside the VA range, manufacturing and industry instead seem to experience, over 1990-2002, a new positive correlation.

In a nutshell, for most emissions the negative correlation is driven to a greater or lesser extent by all three macro sectors. For other pollutants the role of manufacturing and industry appears stronger. Services, though generally associated with a negative correlation, often show a U-shape trend. Even if TP are generally outside the range, this signals a possible critical element for the sector. Only in a pair of cases (SO<sub>x</sub>, NH<sub>3</sub>), the disaggregated evidence adds robustness to the (ambiguous) aggregate analysis, showing a trend which is likely to be characterised by a positive correlation.

Summing up, we may conclude that all NAMEA accounted emissions (on added value), disaggregating the economy into 29 production branches, show a negative relationship with labour productivity over the period of 1990-2002<sup>54</sup>. For some indicators evidence is more robust at a statistical level, for others some inconsistencies arise moreover between logarithmical and non logarithmic specifications when using squared models, which are nevertheless just a secondary test in our analysis. In some cases, a negative correlation arises when correcting the base specifications for serial correlation or when including time period effects in the LSDV model. We may say that major emissions present a sound negative correlation which provides a first validation to our hypothesis and encourages further work.

The picture is, all in all, “positive”. At least over the period observed, which was nevertheless an important part of the economic history of Italy, characterised by a relatively high growth from 1993 to 2001 and by some key restructuring processes of the economy, environmental efficiency is positively correlated with labour productivity. The standard hypothesis of a trade-off between the two dynamics seems rejected by our data. A sort of double dividend arises: technological innovations, at least within certain limits, generate two entangled rents. Explanations are many as discussed in section two. Some environmental “rents” are purely private even from a firm perspective, and are thus worth investing in. Others could be public from a firm perspective but correlated to other environmental and non-environmental private rents, following an impure public good framework. Then, the role of policy cannot be excluded: environmental and innovation policies may generate incentives of reinvesting, even in a complementary way, in, at first glance, diversely aimed technological improvements. Netting out policies, the reason behind the evidence of correlation between the two streams is to be searched within market drivers, from input prices to market demand.

The positive correlation between environmental and labour productivity could partially depend, as debated in EKC literature, on a trade element: a de-location of higher polluting plants and industries in other countries. The literature is not leading to a neat outcome with respect to the effects of environmental regulation on plant location (Levison and Brunnermeier, 2003; Jaffe et al, 1995): environmental regulation driven costs are in any case low with respect to total costs<sup>55</sup>, thus maybe not sufficient to justify a delocalisation decision. This is scope

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<sup>54</sup> We stress that qualitatively the results do not change if we analyse the correlation specifying the labour productivity index as dependent variable.

<sup>55</sup> Some studies also analyse the impact of environmental regulations on location decisions of manufacturing firms. Gray (1997) tests this hypothesis using data on pollution regulations and new plant births in the US over 1963-1987. Information on state laws, abatement spending and other control variables are included. A significant connection is found: states with more stringent environmental regulations have fewer manufacturing plants. The author nevertheless stresses

for further research mainly at sectoral level: the EKC literature has recently started analysing the trade and de-location factors.

#### 4. Conclusions

This paper provides evidence of a complementarity between labour productivity and environmental efficiency (emission intensity of sector added value). Observing a range of production branches, from agriculture to manufacturing and services, the dynamic path over 1990-2002 shows itself to be characterised by complementary dynamics for most and main relevant emissions.

The main added value of the paper is the analysis of the aforementioned hypothesis by exploiting a panel data set based on official NAMEA sectoral disaggregated accounting data, providing both cross section heterogeneity and a sufficient time span. We find that for most emissions, if not all, a negative correlation emerges between labour productivity and environmental productivity. Some evidence also exists in favour of an inverted U-shape dynamic for major pollutants. Overall, then, labour productivity dynamics seem to be complementary to a decreasing emission intensity of productive processes. Taking a disaggregate sectoral perspective, we show that the macro aggregate evidence is driven by sectoral dynamics in a non homogenous way across pollutants.

At sectoral level, evidence shows that for most emissions the negative correlation is driven to a greater or lesser extent by all three macro sectors. For other pollutants the role of manufacturing and industry appear stronger. Services, though generally associated with a negative correlation, often show a U-shape trend. Even if TP are generally outside the range, this signals a possible critical element for the sector. Only in a pair of cases (SO<sub>x</sub>, NH<sub>3</sub>), the disaggregated evidence adds robustness to the (ambiguous) aggregate analysis, showing a trend which is likely to be characterised by a positive correlation. The relative role of manufacturing and services in explaining this pattern is a fruitful stream of research worth analysing in future empirical analyses.

At the basis of the (joint) productivity dynamic, innovation plays a major role, together with economic system restructuring and environmental/innovation policies. Environmental and non-environmental oriented technological innovations could then be said to proceed together, or environmental effects are embodied in normal technological innovations, thus making the boundaries between environmental and non-environmental dynamics more feeble. The motivations of such a correlation depend in any case on the existing links between different innovations, between innovation and its drivers, and between innovation, firm environmental performance and financial/productivity firm performance. They must be searched by empirical research at firm and industry level, adding other and new evidence on top of the contributions which we have presented above.

The extent to which this evidence derives from endogenous market forces, industrial restructuring and/or from policy effects is scope for further research. The role played by policies cannot be excluded. If it is true that over the observed period Italy has not experienced a strong environmental policy evolution, energy taxes play a crucial role, and may have caused indirect effects on emission reduction<sup>56</sup>. Another exogenous market force which may

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that differences between states other than environmental policy might be somewhat influencing results, since evidence is not robust when analysing sub-samples of firms.

<sup>56</sup> Compared to the direct effects which should be associated with exploit environmental emission taxes specifically related to the environmental externality.

have determined these correlated dynamics is the high and increasing price of energy, which reflect the very limited competition characterising Italy in this field.

Further research efforts will be devoted to extending the present analysis in the following directions. First, the stock of total capital (and machinery capital) can be used as an additional or alternative control driver of environmental efficiency. Secondly, the extent to which trade openness, as a proxy of industry trade relationships, is affecting environmental intensity of the economy may be tested. This is a proxy which is somewhat complementary to a test on delocalization effects. With regard to the latter, NAMEA coherent data on flows of direct investments are not available. Capital stocks and trade patterns are quite easily aggregated at the level of our branches. Those are the main added value feasible extensions, besides new estimates that exploit NAMEA 1990-2003 series.

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Table1a. Emissions and added value: descriptive statistics

Variable	mean	min	max
VA/N	53.10	10.77 (B, 1992)	286.70 (CA, 1997)
CO <sub>2</sub> /VA	685.58	4.30 (CA, 1997)	9081.41 (E, 1997)
CH <sub>4</sub> /VA	2.49	0.0019 (J, 2002)	38.17 (A, 1990)
N <sub>2</sub> O/VA	0.189	0.00028 (CA, 1990)	3.06 (A, 1990)
NO <sub>x</sub> /VA	2.23	0.0347 (CA, 2002)	29.83 (E, 1991)
SO <sub>x</sub> /VA	2.56	0.00074 (CA, 2000)	61.01 (E, 1990)
NH <sub>3</sub> /VA	0.543	0.000023 (DF, 1990)	16.48 (A, 1990)
NMVOC/VA	2.28	0.01 (M, 2002)	16.1 (DF, 1990)
CO/VA	2.81	0.055 (M, 2002)	22.22 (DJ, 1993)
PM <sub>10</sub> /VA	0.325	0.0029 (CA, 1997)	2.76 (E, 1990)

N=employees (thousands); VA=added value (Millions of euro liras 1995); Emissions (tons)

Table 1b. Sector branches description

Sector Code	Description
A	Agriculture
B	Fishery
CA	Extraction of energy Minerals
CB	Extraction of non energy Minerals
DA	Food and beverages
DB	textile
DC	Leather textile
DD	Wood
DE	Paper and cardboard
DF	Coke, oil refinery, nuclear disposal
DG	chemical
DH	Plastic and rubber
DI	Non metallurgic minerals
DJ	Metallurgic
DK	Machinery
DL	Electronic and optical machinery
DM	Transport Vehicles production
DN	Other manufacturing industries
E	Energy production (electricity, water, gas)
F	Construction
G	Commerce
H	Hotels and restaurants
I	Transport
J	Finance and insurance
K	Other market services (Real estate, ICT, R&D)
L	Public administration
M	Education
N	Health
O	Other public services

Table 2. Environmental efficiency and labour productivity (log values, years 1990-2002)

	CO2/VA	CO2/VA	N2O/VA	CH4/VA	CH4/VA	NOx/VA	NOx/VA	SOx/VA	SOx/VA	NH3/VA	NH3/VA	NMVOC/VA	NMVOC/VA	CO/VA	PM10/VA
VA/N	-0.508***	1.02***	-0.0732	-0.583*** (-0.476***)	1.45 *	-0.765***	1.09**	-4.74***	-12.98***	2.95***	10.30***	-1.55***	3.14***	-1.43*** (-1.05***)	-0.789**
(VA/N)2		-0.199***			-0.264**		-0.241***		1.07***		-0.955***		-0.2077*		
FEM/REM	REM	REM	REM	FEM (REM) Hausman Test statistics: 5.85	FEM	REM	REM	FEM	FEM	FEM	FEM	FEM	FEM	FEM (REM) Hausman Test statistics: 6.16	REM
Time fixed effects (VA/N)	-0.520*** (LR test does not show structural difference)	Similar to base model	Similar to base model	Not significant		-0.411***	Not significant	-1.38*** (LR test does show structural difference)		-1.917***		Not significant		Not significant	-0.037*** (REM is favoured by Hausman test: -0.043***)
AR1 test (null hp: no serial correlation)	rejected	Rejected (but similar U inverted evidence)	Not rejected in FEM (preferred)	Not rejected in FEM (preferred)	Not rejected in FEM (preferred)	rejected	rejected	rejected	rejected	rejected	rejected	rejected	rejected	rejected	Not rejected
AR1 (VA/N)	-0.898***	Similar to base model	Similar to base model	-0.750***		-0.740***	-1.73*** (-0.689**)	-1.34***	-7.29*** 0.614*** (FEM)	-0.617* (REM - 0.603**)	-7.04*** 0.826*** (REM)	-0.691* (REM 0.609**)	2.51*** -0.207* (REM)	-1.11*** (-0.935***) Hausman Test statistics: 3.68	-0.853***
F test and Chi squared prob.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
N	377	377	377	377	377	377	377	377	377	377	377	377	377	377	377
Non logarithmic specification	FEM: VA/N - 17.70 ***	FEM: VA/N negative and (VA/N)2 positive; high level of linear coefficient	REM: -0.00076*** (LSDV time period effects - 0.00061****)	FEM: -0.061*** (VA/N)	REM/FEM provides the same negative coefficient: -0.043***	FEM: -0.075*** (VA/N)	FEM: Significant coefficients with reversed signs	FEM: -0.125***	FEM: same pattern observed	-0.0017*	REM: Significant coefficients with reversed signs	-0.0197***	FEM: Significant coefficients with reversed signs	-0.045*** (-0.033***)	-0.0075*** (squared specification with both highly significant terms, signs – for linear and + for squared)
Elasticity (non log)	-1.37	/	-0.21	-0.13	/	-0.18	/	-2.59	/	-0.17	/	-0.45	/	-0.85	-1.22
Comment	Negative correlation	inverted U-shape (TP 12,97)	Negative correlation	Negative correlation	U inverted shape	Negative correlation	U inverted shape (ambiguos)	Negative correlation	Positive correlation	Negative correlation	U inverted shape	Negative correlation	Weak U inverted evidence	Negative correlation	Negative correlation; weak inverted U-shape evidence not shown)

Notes: Coefficients are shown in cells: \*10% significance, \*\*5%, \*\*\*1%. For each column we present the best fit specification (linear, quadratic) in terms of overall and coefficient significance. Random or fixed effect specifications are presented accordingly to the Hausman test result. The FEM model estimated is a LSDV model; individual fixed effect coefficients are not shown. The AR1 corrected specification, where it is proper, modifies the level but not the sign and significance of coefficients.

Table 3. Empirical evidence: testing correlation between environmental efficiency and labour productivity for services, manufacturing, industry (years 1990-2002)

	CO <sub>2</sub> /VA	N <sub>2</sub> O/VA	CH <sub>4</sub> /VA	NO <sub>x</sub> /VA	SO <sub>x</sub> /VA	NH <sub>3</sub> /VA	NM <sub>VOC</sub> /VA	CO/VA	PM <sub>10</sub> /VA
Services N=117 (13*9)	negative $\varepsilon$ in linear forms ( $\varepsilon=-1.32$ ), a U-shape emerges from the quadratic (but TP outside the range: 275)	Negative but not significant relationship	$\varepsilon=-2.99$	negative $\varepsilon$ in linear forms (-2,50), U-shape emerges from the quadratic (TP outside the range 136,54)	negative $\varepsilon$ in linear forms (-5,77), U-shape emerges from the quadratic (TP outside the range 103,91)	$\varepsilon=3.47$ (weak inverted U-shape evidence)	negative $\varepsilon$ in linear forms (-5,27), U-shape emerges from the quadratic (TP outside the range 148,41)	negative $\varepsilon$ in linear forms (-6,21), U-shape emerges from the quadratic (TP outside the range 132,64)	negative $\varepsilon$ in linear forms (-2,10), U-shape emerges from the quadratic (TP outside the range 114,45)
VA/N: mean 44,08; range 24,7-98,18									
Manufacturing N=182 (13*14)	Inverted U-shape (TP 31,28); $\varepsilon=-0.594$ in linear regression	Inverted U-shape (TP 94,32)	Inverted U-shape (TP 66,68)	Inverted U-shape (TP 26,5); $\varepsilon=-0.276$ in linear regression	negative $\varepsilon$ in linear forms (-4,79), U-shape emerges from the quadratic (TP within the range 170,6)	$\varepsilon=4.61$ (inverted U-shape evidence in quadratic, TP 97,76)	negative $\varepsilon$ in linear forms (-0,927), U-shape emerges from the quadratic (TP outside the range 210,97)	negative $\varepsilon$ in linear forms (-0,396), U-shape emerges from the quadratic (TP within the range 28,61)	$\varepsilon=-0.46$
VA/N: mean 47,15; range 21,61-203,84									
Industry N=234 (13*18)	Inverted U-shape (TP 35,12); $\varepsilon=-0.451$ in linear regression	Inverted U-shape (TP 89,25)	Inverted U-shape (TP 61,90)	Inverted U-shape (TP 26,80); $\varepsilon=-0.691$ in linear regression	Though negative $\varepsilon$ in linear forms, U-shape emerges from the quadratic (as for aggregate level)	Though positive $\varepsilon$ in linear forms, inverted U-shape emerges from the quadratic, TP 130,76 (as for aggregate level, opposite to SO <sub>x</sub> )	$\varepsilon=-0.876$ (weak statistical evidence of U-shape in quadratic, TP 8,24)	Inverted U-shape (TP 31,60); $\varepsilon=-0.540$ in linear regression	$\varepsilon=-0.77$
VA/N: mean 61,34; range 21,61-286,7									
comment	The negative correlation emerging from the aggregate analysis is present and driven by all three macro sectors; inverted U-shape TP are within the range (manufacturing) or even outside the lower VA level (industry)	The negative correlation emerging from the aggregate analysis appears driven by manufacturing /industry (note: agriculture though relevant is not estimated due to data paucity)	The negative correlation emerging from the aggregate analysis appears driven by all three macro sectors: industry/manufacturing present inverted U-shape with TP within the range, while services a consistent negative link	The negative correlation and EKC evidence emerging from the aggregate analysis appears driven by manufacturing/industry: services show some evidence for a U-shape, though at current VA levels the relationship is still negative	The ambiguous correlation emerging from the aggregate analysis appears driven by manufacturing and industry showing U-shape with TP within the range and services showing also U-shape, but with TP outside the range	The (weak) EKC evidence emerging from the aggregate analysis appears driven by manufacturing/industry more than services (note: agriculture though relevant is not estimated due to data paucity)	The negative correlation and weak EKC evidence emerging from the aggregate analysis appears driven by all sectors showing quite homogenous trends	The negative correlation and weak EKC evidence emerging from the aggregate analysis appears driven by industry and services: services and manufacturing show U-shapes with TP outside and within the range	The negative correlation emerging from the aggregate analysis appears driven by all sectors

Notes: results shown are related to log specifications; linear and quadratic specifications are tested; results are shown for those significant in terms of coefficients and overall regression.

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