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What Drives Environmental Innovation? Empirical Evidence for an Industrial Manufacturing System

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What Drives Environmental Innovation?

Empirical Evidence for a District-Based Manufacturing System[♦]

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Abstract

Technological innovation is a key factor for achieving a better environmental performance of firms and the economy as a whole, to the extent that helps increasing the material/energy efficiency of production processes and reducing emission/effluents associated to outputs. Environmental innovation may spur from exogenous driving forces, like policy intervention, and/or from endogenous factors associated to firm market and management strategies. Despite the crucial importance of research in this field, empirical evidence at firm microeconomic level, for various reasons, is still scarce. Microeconomic-based analysis is needed in order to assess what forces are lying behind environmental innovation at the level of the firm, where innovative practices emerge and are adopted. The paper exploits information deriving from two surveys conducted on a sample of manufacturing firms in the Emilia Romagna region -Northern Italy- in 2002 and 2004, located in a district-intense local production system. New evidence on the driving forces of environmental-related innovation is provided by testing a set of hypothesis, concerning the influence of: (i) firm structural variables; (ii) environmental R&D; (iii) environmental policy pressure and regulatory costs; (iv) past firm performances; (v) networking activities, (vi) other non-environmental techno-organizational innovations and (vii) quality/nature of industrial relations. We estimate various input and output-based environmental innovation reduced form specifications in order to test the set of hypothesis. The applied investigation shows that environmental innovation drivers, both at input and output level, are found within exogenous factors and endogenous elements concerning the firm and its activities/strategies within and outside its natural boundaries. In the present case study, usual structural characteristics of the firm and performances appear to matter less than R&D, induced costs networking, organisational flatness and innovative oriented industrial relations. Environmental Policies and environmental voluntary auditing schemes exert some relevant direct and indirect effects on innovation, although evidence is mixed and further research is particularly needed. Although this new empirical evidence is focussing on a specific industrial territory, results concern a large set of hypothesis on potential driving forces of innovation. We thus provide food for discussion on firm environmental innovation strategies, and research suggestions for further empirical works.

JEL codes: C21, L60, O13, O30, Q20, Q58

Keywords: environmental innovation, environmental R&D, manufacturing sector, local system, environmental policy, networking

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1. Environmental Innovations and environmental policies in industrial settings

1.1. Increasing efficiency in the use of resources

Growing evidence suggests that advanced economic systems operate with a decreasing intensity of energy and materials per unit of output. For energy and materials, these trends can be observed over the very long run. Phases of emerging scarcity of "productive" natural resources stimulated significant demand and supply responses that, at the cost of economic turbulence and difficult adjustments, ultimately entailed extensive efficiency gains in the use of resources. The historical regularity of these processes suggested the idea that resource-use efficiency and de-materialisation are the result of technological innovation which responds to scarcity 'revealed' by resource prices and, in the absence of resource markets, by public policies. In countries of earlier industrialisation, energy consumption per unit of GDP has been already decreasing since the end of 19th century (United Kingdom) or since the 1920s and 1930s (United States, Germany and France). During and after the 1970s, these trends spread to all the advanced countries and to some less developed countries. Shocks on energy and commodity prices of the 1970s stimulated energy efficiency, resource saving and innovation policies.

Similar developments took place in the case of industrial materials. In the mineral and metal sector, for example, where metals with increasing and decreasing intensity of use (ratio of consumption to GDP) usually tend to coexist, the 1970s represented a break point and a declining intensity of use tended to generalise to almost all the metals. Even in this case structural change, with a significant delocalisation of traditional heavy industries to emerging countries, and technological innovation worked together.

In general, the factors behind macro-level decoupling between economic growth and resources can be: (a) market factors, i.e. change in relative prices of basic commodities; (b) technological innovation at the macro and micro level, including structural changes of the sector composition of the economy and 'industry migration'; (c) public policies. The three are dynamically interrelated. Lagged effects and the interactions between prices, policies, and technological innovation can partly explain the uncertainties in understanding of environmental efficiency long run phenomenon. The attainment of a higher energy and material efficiency typically calls for investment in capital goods. Therefore the adjustment to a relative price change may result very sluggish and even very efficient technologies already available can be introduced slowly. Public policies have had also a significant role in filtering the effects of international price shocks, supporting technological changes, and, on the negative side, subsidising energy- and material-intensive sectors.

Concerning the current European situation, we observe a mounting interest in environmental (less polluting) technologies, partly depending on the contribution they can make to complementarily reach the "Lisbon Objectives" on growth and innovation and the "Gothenburg priorities" on sustainable development (IPTS, 2004)[1]. We may affirm that a shift of emphasis in environmental

[1] The IPTS report stems from the 2004 Commission communication "Stimulating technologies for sustainable development: an environmental technology action for the EU", which derived from a 2001 European Council

policy, from strictly regulatory targets to innovation-oriented and more comprehensive goals, has been effectively taking place. The role of environmental innovations, intended as techno-organisational, social and institutional changes leading to an improved quality of the environment (Huber, 2005, 2004; Kemp, 1997) is obviously one of mitigating the growth-environment trade off[2].

1.2 Local environmental pressures, district-based innovation and policy responses

The issue of environmental innovation in district-oriented local productive system is particularly important given the high density of firms in district industrial devoted areas. This is extremely relevant for some industrialised Italian Regions, like Emilia-Romagna, since cluster or districts of firms may generate critical harmful local "hot spots" in emission and waste production (Montini and Zoboli, 2004). The local relevancy is particularly serious for externalities like river pollution and (urban) landfills. This negative environmental feature could be counterbalanced by the high innovative propensity of district firms that, exploiting networking relationships, knowledge spillovers due to proximity and internal sources, may dynamically increase the environmental efficiency of the district/productive area[3]. The relative rate of growth of externalities and innovation is crucial for determining whether a *Delinking* between growth and environmental externalities is occurring or not[4]. Environmental Innovative capacity, endogenously driven and/or spurred by policies and networking spillovers and agreements, is currently the key issue. Environmental innovations are particularly crucial in industrial local frameworks since they often give rise to a "double externality", providing on the one hand the typical R&D spillover and on the other hand reducing environmental externalities.

Specifically concerning manufacturing, pollutant emissions from the manufacturing industries are main determinants for the general pollution affecting the environment, in Italy and in the European industrial environment. Manufacturing industries apart from the energy production industry, account

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that requested the preparation of a report "assessing how environmental technology can promote growth and employment".

[2] See Loeschel (2002) for a detailed survey on technological change in economic models of environmental policy.

[3] Aggeri (1999) calls those informal agreements "innovation-oriented voluntary agreements", where pollution is diffuse, uncertainty is high and innovation becomes the central feature". He stresses that "at the start of the process, there is enormous confusion about the nature and scope of pollution, the identity of the polluters, the validity of scientific knowledge and therefore about the solutions that should be implemented. The solution to these controversies cannot be envisaged without cooperation between various actors over long periods of time and at a cost of considerable effort regarding innovation" (p.706).

[4] Delinking connects to the largely debated issue of environmental Kuznet curve. Empirical evidence shows that an inverted U shape curve with an observable turning point is characterising some externalities (some local-regional emissions, in-water effluents), but not other pollution outcomes (CO_2, waste). Pasche (2002) shows rather pessimistic results, which rely on a theoretical model investigating dynamic evolution of income and technology. Environmental technical progress and structural change can lead to positive growth rates with a constant or decreasing pollution. Hence the results are compatible with the EKC hypothesis. But the phenomenon is temporary, since in the long run a strict trade off between pollution and growth emerges. The outcome is representative of the debate over the complex and critical dynamic evolution of technology, growth and pollution.

for a relevant part of total emissions for respective species[5]. They are the principal offenders in the case of methane (CH_4); the transport sector is the most polluting in the case of carbon monoxide (CO), the nitrogen oxides (NO_x) and the non-methane volatile organic compound (NM-VOC). Six air pollutants are considered in the Italian official environmental data. Data refer to air pollution emissions from household consumption (transport, heating and others) and production activities (agriculture, industry and services). Upon examination of the macro sources of emission in Italy it appears that the manufacturing industry is primarily responsible for carbon dioxide pollution and accounts for about 40% in the sulphur oxides emissions too.

Strictly relevant for our case, the last decoupling indicator for waste suggested by OECD (2002) focuses on manufacturing processes, and it is strictly related to the concept of resource efficiency, the amount of waste generated by manufacturing industry versus manufacturing value added can in fact be interpreted as a partial measure of their resource efficiency or productivity[6]. The available data shows that no decoupling has occurred during the period 1990-97. No decomposition is proposed, although it is straightforward that the main factors influencing it are overall industrial structure and the presence of clean and material-saving production processes and technologies. As for the choice of the denominator, it seems appropriate to use value added, because it is the main driving force behind manufacturing production of waste. Montini and Zoboli (2004) interestingly show that the set of correlations between manufacturing density and air pollution indexes is higher than for other social indicators like population density and income (correlations range between 0,37 (NH3) and 0,90 (CH4)).

The specific evidence for Emilia Romagna, which is the Region under consideration here, suggests the importance of local industrial concentration for the local environmental pressure (Montini and Zoboli, 2004). The high potential impact depends on either specific features of the sector production technologies or spatial concentration of industrial activities. It also appears that industrial districts are quite frequently in the top ranking positions of the most polluted Local production systems. Examination of rank by per capita emissions shows that two Emilia Romagna industrial districts, in Sassuolo and Castellarano Municipal areas, with high specialisation in other non metallic mineral products are the most polluted with regard to sulphur oxides (SO_X), nitrogen oxides (NO_X), carbon dioxide (CO_2) and nitrous oxide (NO_2) and they have absolute per capita values which are double, or even more, of the third ranking areas. In addition to this, the worldwide known export-oriented ceramic district of Sassuolo is top ranking in terms of the per area emissions of all pollutants.

Not surprisingly, then, the historical development of environmental policy in Italy have significantly involved manufacturing industries in industrial districts, as sector-based policies on a specific issue (water quality, waste), agglomeration of specific environmental policy and more recently local integrated policies addressing the state of the environment in the local system. Three policy phases can be defined. The first phase (early eighties) was marked by a social pact involving

[5] Jaffe et al. (1996) present a ranking of "environmental efficiency" concerning manufacturing and non manufacturing sectors, relatively to the US environment.

[6] On the other side of the coin, this indicator can be interpreted as a measure of waste-intensity of the manufacturing sector.

the full acceptance of the detrimental environmental impact due to the priority given to development a social goal. The second phase (eighties) marked a change in attitude on the part of local institutions under pressure by the local population concerned with environmental externalities. The third phase starting in nineties is the one where compliance with environmental legislation accelerated even in marginal enterprises and local institutions increased their support towards a co-operative approach to policy implementation. Regarding the third phase, the key points are (i) how far districts industrial development proceeds towards a co-operative approach and management of environmental policy at the district level (networking/spillover dynamics), by exploiting traditional districts advantages (density of interactions, Marshallian externalities, social capital dynamics); (ii) the perception by companies of environmental innovation as a source of competitive advantage at the National and international level (Porter-like Hypothesis[7]); (iii) what the primary driving forces of environmental innovation are.

The paper empirically addresses those three critical points. Results are crucial both for the development of locally sustainable industrial districts and more generally for increasing the competitiveness of firms in markets by techno-organisational innovations and high performance practices. Despite the great interest on districts in Italy, available information on the investments and innovations related to environmental issues is rather limited. We may briefly say that most initiative for introducing low impact technologies have been taken in sectors/districts like machineries, leather, and ceramic. Nevertheless, most innovations tend to be end of pipe rather than structural: investments in clean technologies are rather rare and can be observed only in few districts and firms. Environmental management systems (EMAS, ISO14001) are not widespread on average and in industrial districts as well (see Iraldo (2002) for a recent assessment on the EMAS dynamics in Italian districts)[8]. The situation is clearly in transition. Starting from end of pipe solutions to comply with traditional policy, industrial districts firms are slowly moving to more advances approaches based on clean technologies and environmental management schemes. Innovative reactions to environmental problems, however, are still characterised by a limited willingness to exert a leading role; the possibility of developing environmental competitive advantages *à la* Porter seems to be currently limited.

2. Empirical analyses: a survey

We here briefly list and comment the main recent empirical contributions dealing with the interconnected issues of environmental innovation, environmental policy and firm performances.

[7] For a detailed critique of Porter hypotheses we refer to Jaffe et al. (1996). Mohr (2002) theoretically addresses the hypothesis that environmental regulation may benefit affected firms. 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.

[8] 148 Italian organisations were registered to EMAS in 2003, of which 87% were northern Italian companies. Food represented the most represented sectors, with 26% of total EMAS companies. ISO 14001, the most known and used voluntary ecolabel certificate, witnessed an increase of 1000 units in 2002/2003, leading to a total of 2700 certificates, also mostly present in Northern Italy. The number of both certifications is nevertheless strictly increasing. The Sassuolo district of ceramics is the only experience of EMAS certifying the entire district industry.

We subdivide the literature in three parts: (i) investigations using environmental Innovation output and/or input indexes as dependant variable, which are the primary interest for our applied analysis. We also take a look at contributions focusing on (ii) firm/sector pollution indexes, and (iii) firm performances as dependant variables, since both analyses are useful to give a comprehensive outline of the entangled issues at stake. In fact, since innovation, performances, policy and pollution are intrinsically co-evolving and co-determinant variables at firm level, each contribution may focus on a specific piece of the conceptual "model", depending on both data availability and research aims.

Concerning research line (i), Jaffe and Palmer (1997) study environmental innovation by defining R&D and patents as dependant variables, at industry level, then analysing the two output and input innovation proxies separately. The study aims at empirically investigating the relationship between innovation and policy, rooting on the (ambiguous) set of "porter" hypothesis. The weaker hypothesis says only that regulations will stimulate certain kinds of innovation, but they may worsen firm outcomes. They find, in a panel framework (1976-1991), where two reduced form equations for R&D and patents are modeled, that higher lagged abatement costs lead to higher R&D expenditures. However, when the output of innovation is used (patent), evidence is less robust on the mentioned link. Overall, they conclude "data at the industry level are mixed with respect 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. It is worth noting that they include all R&D and patents, whether environmentally related or not.

One of the most recent contributions is that by Brunnermeier and Cohen (2003) who 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 destruction and containment, recycling and reusing, acid rain prevention, waste disposal, alternative energy sources, air pollution, water pollution) and found, exploiting a simple reduced form, that it responded to increases in abatement expenditures, while monitoring and enforcement activities associated to regulations do not impact innovative strategies[9]. Internationally competitive industries are also more likely to innovate. It is worth noting that although data are based on firm specific information deriving from surveys, only data aggregated at the two or three digit are available to the public. It is therefore not firm level evidence, as we provide in the present paper, but a panel on 146 US manufacturing industries.

In the European setting, evidence on environmental innovation is recently provided by Frondel et al. (2004), who exploit OECD survey data for Germany at firm level (manufacturing industry)[10], in order to investigate whether environmental auditing schemes (voluntary management-oriented

[9] Parry (2001) questions the primary role of induced innovation as a goal of environmental policy, from a theoretical Pigovian based perspective. The welfare gains from induced innovation seem to be lower with respect to welfare gains linked to reduced pollution. This does not mean that innovation is unimportant: in the long run innovation can greatly reduce the costs of environmental protection. But from a pure efficiency perspective, innovation should not be the main consideration in policy design.

[10] Another contribution exploiting German data is Horbach (2003). Though the establishment dataset presented is very representative of all manufacturing sectors, the low detail concerning innovation and other firm factors is an example that specific (survey) studies focussing on industrial realms at a micro-level are absolutely necessary for getting high-quality information and consequently carrying out robust quantitative analysis.

organizational innovation) and pollution abatement innovation are correlated. Using simple and bivariate probits, they complement past evidence by adding the role of management schemes into the fore. The driving forces of voluntary schemes and pollution abatement technologies are jointly assessed; covariates are grouped in three sets: motivations (corporate image, compliance, policy stringency, cost savings), policy tools (voluntary, subsidies, market, regulatory, EMS, information), pressure groups (unions, green organizations, authorities). 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. All in all, it is surprising that various environmental policy tools market based and regulation based, appear not to be important for triggering either EMS or abatement innovation. We note that policy variables are elicited from firms which report a degree of "stringency/pressure" for environmental policy. Apart from the "pressure" role of public authorities, surprisingly assessed as moderately stringent or not stringent by most firms, external forces do play a minor role (also consumers, union and green movement's pressures are not relevant). Industry effects are also minor, as well as size and R&D, as explanatory factors of innovations. Overall, the set of determinants is not large, pointing to the need of further investigations using more detailed data, which cover different driving forces (probably omitted in the paper).

Rennings et al (2003) also provide evidence on Germany, deeply focusing on auditing schemes like EMAS and correlated environmental organisational innovations. The main hypothesis they test is the influence of the "maturity" of EMAS (depending on age of EMAS, 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. The main weakness of the study is the reliance on only EMAS adopting firms: facilities which do not adopt EMAS are not included in the sample.

Turning back to US, 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) using a 24 years long panel (1970-94) where the dependant variable is the number of patents granted concerning environmental innovation (supply and demand oriented technologies). Energy prices are the primary explanatory variable. Statistical units are 11 classified technology groups. He 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 more important tool of intellectual assets protection. As a result the correlation between R&D and patents vary across industries.

Concerning line (ii) 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. firm average size) and regional characteristics, provides 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. A negative and significant relationship is also found for the variable capturing formal regulatory pressure at regional level. Results thus 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) paper 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 effort (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 instead 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.

Millock and Nauges (2003) 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.

Finally, as far as line (iii) is concerned, 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 (both variables are for 1989 only, while the dataset is a hybrid, with dependant variable and most independent factors for 1989, with the addition of some lagged explanatory factors). 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, derived from the Tobin's q equation transformed, to decompose tangible and intangible elements in firm valuation. The main contribution is to include "environmental performance" as explanatory variables in estimating intangible assets. Empirical results for the equation for Tobin's q show that both variables of environmental performance are associated to negative and robust impacts. The two variables remain significant with negative signs in the intangible assets equation: from the average level in the 223 firms sample, they estimate an average liability (asset loss derived from environmental bad performance) of about 9% of the replacement value of assets.

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 portfolio 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. Data are on 368 firms for years 1987-88. 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[11]. 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. A widening gap, 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 could characterise the future dynamics of local industrial areas, if we refer to our concern. This is a key issue for the current debate on local systems in the European and Italian environment.

Gray and Shadbegian (1995) instead use as performance indicators total factor productivity and growth rates for plants in paper (101 units), oil (101) and steel (51) industries over 1979-1990, testing the impact of environmental regulations and pollution abatement expenditures. They find that $1 greater abatement costs is 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[12]. 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.

Gray and Shabdegian (2003) further analyse the link between productivity and abatement costs, testing whether the impact vary 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 are also experiencing 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 only mills, in the key technological distinction proposed by authors for the sector.

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

[11] The correlation between environmental and other form of innovations is a hypothesis we test in the paper.

[12] Becker (2004) provides evidence that capital expenditures and operating costs of manufacturing US plants from 1979 to 1988 are positively driven by the stringency of clean air act regulations, differentiated by counties. Size effects are also found significant.

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 finding 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 generally a weak impact of the policy on the 80% SO_2 decline.

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 that differences between states other than environmental policy might be somewhat influencing results, since evidence is not robust when analysing sub samples of firms[13].

After presenting some relevant recent contributions, we observe that the added value of the present paper is to provide new evidence on the driving forces (determinants) of environmental innovation using a specific dataset rich in information on firm strategies and production structure. The dataset is very detailed since it stems from a direct survey and only partial suffers from cross sectional bias, insofar it is built on two separate and consequential direct surveys. It is worth noting that evidence grounding on firm level data possessing richness in details and representativeness is rare.

Two consequential surveys concerning the same sample of firms allow us to carry out a more robust assessment of environmental innovation determinants. We here exploit two waves of a cross sectional investigation on the same firms (in 2002 and 2004), eliciting data respectively on 1998-2001 and 2001-2004 trends, for investigating what the driving forces of environmental innovation are. The driving forces of innovation are here defined as a set of independent variables, related to (i) firm structural characteristics (size, sector, international openness), (ii) environmental R&D, investments and direct costs, (iii) environmental policy; (iv) industrial relations (v) non environmental techno-organizational innovations, (vi) networking activities in districts. Some covariates are lagged depending on data availability; the use of lagged drivers is often suggested for addressing the causality issue. It is possible to affirm (Foulon et al., 2002; Magat and Viscusi, 1990; Lanoie, 1992) that the use of lagged determinants is one option to cope with the issue of simultaneity, assessing causal effects in a more robust way. Panel data frameworks, representing in principle a better environment in the one hand (unobserved heterogeneity is dropped off), may be associated on the other hand to practical elicitation problems, when the applied analysis focuses on different for of techno-organizational innovations and intangibles factors of production, often quasi-fixed or slowly evolving factors over time (Huselid and Becker, 1996; Brynolfsson et al., 2002). Official dataset are

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[13] Brunnermeier and Levinson (2004) also deal with location strategies. They questions the evidence that environmental regulations have insignificant effects on firm location decisions, by surveying more recent and robust studies relying on panel data sources. Dean et al. (2000) instead analyse the extent to which environmental regulations act as barrier to the formation of small manufacturing firms.

not available and the setting up of panel frames by specific surveys is theoretically possible but practically very difficult, given the quasi-fixed or slowly evolving feature of most factors.

Although specific to the industrial system here studied, our results may allow a generalisation concerning the northern Italian and European industrial situation with respect to the recent trends in environmental innovation. The analysis also opens some new research directions, widening the vector of potential driving forces of environmental innovation in complex and evolving industrial systems. Jaffe and Palmer point out the need of further applied micro-oriented research (1997, p.618): "given the inconsistency between our findings for R&D and for patents, the highly aggregate nature of the data in this study, and the shortcomings of using compliance expenditures as a measure of regulatory stringency, further research is necessary before these results can be considered conclusive. It is to these topics for future research we now turn. [...] Perhaps the best way to overcome the aggregated nature of the data used in this study and to develop a better understanding of the nature of the relationship between regulation and innovation would be to conduct some focussed industry study".

We here aim at providing additional new evidence with detailed firm data covering a full comprehensive set of explanatory factors for innovation[14]. The value added of the paper is thus high, as it sheds light on an evolving issue like environmental innovation dynamics and its determinants, by exploiting very recent and rich information on a historically structured manufacturing area rich in districts and innovative firms.

3. Innovation dynamics in an industrial system

3.1 Data and Context

The Province of Reggio Emilia is located in the Emilia-Romagna Region. Emilia Romagna is an area of Northern Italy characterised by a high density of industrial districts, it shows a very high level of per capita GDP (around 27.000 in 2003); and with four millions residents represents the 7% of the Italian population[15]. The industrial system of Reggio Emilia is a complex one, primarily characterised by a high degree of dynamism of the system, with important variations and exceptions to this general feature.

[14] We also quote Jaffe et al. (2002, p.62), from their survey paper on environmental technological innovation: "what is clear is that many relevant issues cannot be resolved at a purely theoretical level or on the basis of aggregate empirical analysis alone".

[15] The Region is heavily industrialized and ranks third concerning value added per capita in Italy. As far as a Provincial ranking is concerned, Reggio Emilia ranks at the seventh place in Italy.

Firms preliminarily included in the universe are those belonging to the manufacturing sector (257 firms, see tab.1a) with at least 50 employees and located in the province of Reggio Emilia in year 2001. The first survey carried out in 2002 was made up of a questionnaire addressed to the Management. The firms responding to the survey were 199, with a reply ratio of 77,4% of the entire population. Firm distribution by sector and dimension shows a very limited bias.

Innovation intensity is high both concerning technological and organisational innovations (Antonioli et al., 2004). Since 1998 the most part of firms decided to introduce organisational and technological innovations. We highlight the strong incidence of both product and process innovations that, even separately, are recorded in a percentage of firms near to 70%.

A first result that clearly emerges from data exploration is the strongly complementary character of the introduction and presence of innovations. Technological and organisational innovations are seldom introduced alone. Second, innovative intensity seems to be a growing function of dimension, mainly in terms of plant dimension more than in terms of firm dimension. Innovative processes are particularly intense in medium and medium-large firms (between 250 and 999 employees), while it is less pronounced in firms below 250 employees. It is worth noting that the local production system witnesses the presence of both (historically) higher-innovative higher-performing sectors (chemical, machineries, ceramics) and lower innovative lower performing ones (textile, food), with respect to the manufacturing average. Data on "environmental performance" and innovation are not available at a specific disaggregated firm level.

The survey on environmental innovation was carried out by administering a short focused questionnaire to the 197 firms who had joined the first survey. Telephone interviews were made in November 2004. We ended up with 140 out of 197 firms joining the second survey, showing no significant distortion by sector and by size, as shown by tab.1b. The study is thus based on a very representative final dataset.

The questionnaire elicited information on (i) process and product technological innovation introduced over 2001-2003, aimed at increasing environmental efficiency in (a) emission production, (b) waste production and management (c) material inputs, (d) energy sources. Then, we asked whether those innovations were (a) produced from within the firm (b) stemming from co-operative agreements with other firms, (c) stemming from co-operative agreements with research institutions, (d) acquired from other firms. Whether innovation was associated to patenting activity was also asked. Further, the adoption of voluntary environmental auditing schemes (environmental corporate management) was elicited (European schemes like EMAS, ISO9001, etc...). As far as environmental policy is concerned, a question was devoted to whether the firm was subject to policies on (i) emissions and (ii) waste/energy. We asked for how many years the policy had been implemented. Three more questions elicited the expenses on environmental R&D, capital investments and direct costs (current costs plus tax payments, etc..) over 2001-2003. Finally, we asked whether the firm had exploited governmental environmental grants (subsidies) over the past 3 years. It is worth noting that the questionnaire added value is high since in the Italian and European framework information on environmental innovation (our dependant variable) and other determinants (including policy and

R&D) is scarce, if not absent at all, at firm level. This is even truer if we deal with local production systems characterised mainly by medium and medium-large firms. Survey methods are the only way to recover the necessary information for applied analysis at a micro level.

A proof of the good degree of representativeness for the two surveys comes from the following test (Cochran, 1977) which allows determining, given the universe and the final sample, in addition to a given level of probability, the maximum error we are experimenting.

The formula is:

$n = N/[(N-1)theta^2+1]$;

where n is the sample, N the universe, and theta the error we face (i.e.. 0,05, 0,04).

As far as the first is concerned, n=199 and the universe is 257; the sampling error is equal to 0,046. For the second survey, n=140, so taking N=199 gives barely 0,04, while taking the full universe 0,055. Values of 0,05 or not much distant from that threshold level are generally considered as good.

3.2 Input/output based Environmental Innovation and policy: a preliminary descriptive analysis

Concerning the specific data on environmental issues, we note and comment the following descriptive elements for the 140 firms (tab.2).

The 79% of firms reported to have adopted environmental related innovation (process/product innovations increasing environmental efficiency in various directions) over the period considered (2001-2003) at least in one of the environmental areas. Concerning the four specific environmental areas, the adoption of innovation is respectively of 49%, 42%, 28% and 46%[16]. Finally, firms adopting all four forms of innovations are less than 10% of the sample.

Innovation intended as the adoption of (voluntary) auditing schemes (EMAS, ISO[17]) concerns 26% of firms. We can partially compare this outcome with that of Frondel et al. (2003) who find half firms of their sample adopting EMS. Among those auditing-oriented firms, we note that various ISO management schemes are more common (20 firms having ISO9000 and 17 firms ISO14000) than EMAS (6 firms). This is compatible with the more stringent rules and the European level of EMAS scheme. Only 8 firms have introduced both EMAS and ISO environmental certification schemes. Those schemes lie within the broad and still vague realm of "environmental organisational innovation" (Bradford et al., 2000).

[16] Huber (2005, 2004) presents some descriptive evidence on the relevancy of various realms (i.e. energy, emission) of technological environmental innovation, also providing a good summary of environmental technologies.
Frondel et al. (2004) consider a sample of 899 German manufacturing firms, finding that half of 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. Concerning process innovations, the shares of structural changes and end of pipe technology are respectively 56% and 42%.

[17] EMAS is the European management auditing schemes adopted by the EU in 1993. A formal policy and programme of site measures and a management system were included in this standard. The International Organization for Standardisation (ISO) then developed a series of environmental auditing/labelling standards over 1996-1998, known as ISO14000 series (ISO14001 is the most known, and it is the only normative standard in the 14000 series; it serves as the compliance standard for EMS certification. Others ISO are: 14010-11 for auditing guidelines, 14040-41 for life cycle assessment guidelines, 14020 for labelling issues).

The share of firms reporting an environmental-related patent activity is very low (2%). This figure was honestly expected, given the low number of patents registered by Italian firms and the specific realm here analysed. Though the outcome is compatible with the historically low number of patents produced by Italian firms (with the exception of machineries sector), it is worth observing that there may exist an incentive, in district-oriented local system characterized by a majority of small and medium firms, to under-patenting innovation given uncertainties concerning the defense of intellectual property rights. Thus, differently from other studies on the determinants of innovation (Brunnermeier and Cohen, 2003), patenting does not appear to represent the best proxy for innovative capacity and adoption in the present case. The imperfect measuring of innovation by patents is commented by Gu and Tang (2004), who stress that some firms protect property rights by trade secrets and copyrights instead of patenting.

It is worth examining the sources of innovation. This is new information concerning environmental innovation. We asked whether adopted innovations were developed (i) entirely within the firm; (ii) by cooperating with other firms, (iii) by cooperating with research institutes, or whether they were (iv) acquired from other firms in the market. Summing up, innovation developed by firms themselves is highest for material input related innovation (62% of innovating firms) and lowest for emission reduction (34%). Cooperation in terms of networking with other firms is quite high and mirroring the previous case, with percentage ranging from 28% (material input) to 41% (emission reduction). The share of firms developing innovation by cooperating with research institutes/universities is very low (2-3% in the different cases). Finally, innovations introduced but developed by other firms (thus acquired) range from 8% (material inputs) to 16% (emission reduction). We see that the role played by networking dynamics, which is crucial in industrial district areas, is relevant, as expected, also for environmental issues. The very low level of research institutes involvement should suggest a reflection for future policy actions at regional level, since marginal added value may stem from increased firm-research institutes cooperation.

As far as innovation inputs are concerned (environmental R&D and environmental capital investment), data shows that 61 firms report positive R&D related to environmental issues, and 72 positive capital investments. The mean values are, in percentage of annual turnover, 0,64% for R&D and 0,95% for investments. It is worth noting that a 15%-20% of firms did not report values for R&D, investment and costs. Considering then all 140 firms (inserting zero values for non responding firms[18]) the mean value is instead barely 0,6% and 0,8% of turnover (with maximum values of 10%) or 2000 per employee. Those lower values may represent a cautious estimate, in absence of official datasets. As a rough term of comparison, the Italian industrial R&D value elicited by the *Third EU Community Innovation Survey* is about 3000 considering only formalised R&D, and more than 8000 including also expenditures on innovative man-made capitals, skilled labour training and know-how acquisitions (data for year 2000, per employee).

[18] We argue that most firms not reporting values are likely to have very low or even zero values for environmental R&D, investments and expenditures. This hypothesis helps providing a precautious estimate of such figures.

Concerning environmental direct costs and expenses (regulatory driven, current expenses, etc..) the reported mean value is 0,86% of turnover for reporting firms and 0,7% considering all firms as above. 16% is the maximum value observed.

Moving to policy issues, the percentage of firms reporting to be subject of environmental regulatory pressure is 66% for emission oriented policy and 70% for waste oriented policy. The mean values concerning the number of years for which a firm has been subject to environmental policy are respectively 7,4 and 8,8, with maximum values of 25 and 27 years. We recall that, given the relatively recent Italian experience on environmental policy and the absence of effective market driven instruments so far[19], it was not possible to test, for instance, the relative effectiveness of various market and non market environmental policy tools. We opted for the number of years as one of the proxy for regulatory pressures (see more below). Finally, only 5% of firms received public grants concerning investments in environmental innovation.

To conclude the paragraph we descriptively examine the extent to which innovation is influenced by size and sector. Concerning output innovations, it does not emerge a clear size effect. Although smaller firms are associated to the lowest (mean) index for all environmental indexes, the percentage of firms involved in environmental innovations is only slightly, if not, increasing by size. Concerning emission-related innovations, firms between 250 and 499 show the highest percentage. Waste innovations are definitely immune from size effects. Energy related innovation instead present an inverted U shape by size: the "innovation peak" is for firms between 500 and 999 employees, the decreasing for the largest ones. When analysing firms that present all four forms of innovations, we note instead a monotonous size effects, from 2%, for smallest firms, to 30%, for largest firms.

Environmental auditing is finally presenting a moderate increase by size, though firms with more than 250 employees show a constant percentage index for all classes. Empirical evidence for Germany (Frondel et al., 2004) confirms that ISO typologies dominate EMAS (25% of firms in the German case study, mainly concentrated in the chemical industry), and the latter is more likely to be present above a certain facility size.

By sector, we first note that Textile, as expected (it is historically a low innovation sector), shows the lowest involvement in environmental issues within manufacturing. Concerning the most relevant sectors for numbers of firms, the investigation shows that emission related and material inputs innovations are more likely to characterise the chemical sectors (60% and 50% of firms), while waste management related innovations the machineries sector (57%). Ceramics has the highest score (60%) for energy efficiency innovations.

Turning attention to R&D, investments and environmental costs, elicited as percentage of turnover, once again size effects are not dominating figures. R&D is not associated to any size effect. For capital investments, an inverted U shape arises, with largest firms showing the lowest value. As far as costs are concerned, no size effect is clear, although the highest value is for the largest firms. By sector, we report the highest and lowest observed values: chemical and textile for R&D (1,3% and

[19] Pigovian-like taxes have been often proposed (carbon tax) but never really implemented, while a first European Emission trading scheme for CO_2 is starting in 2005 with a first pilot phase. Whenever present in Italy, economic tools are set at very low levels thus lacking incentive effects.

0,0%), paper-publishing and textile for capital investments and also for environmental costs (respectively 2,6%/0,0% and 1,7%/0,0%).

4. Empirical analysis

4.1 The set of hypothesis

The applied analysis provides new evidence on the driving forces of environmental innovation in industrialised settings. Results are to be validated by further studies, which take into account different zones and sectors, and/or larger datasets. We test the following set of main hypotheses[20]:

(1) *Size positively influences environmental innovation.* This is a usual hypothesis in studies of determinants of innovative behaviour and regulatory costs (Dole, 2001). Economies of scale may spur innovative strategies and reduce the cost burden: either/both largest firms may bear the fixed costs of investing in innovation and/or large firms complementarily adopt technological and organisational innovation (HRM, high performance practices). In this latter case economies of scale refer to increasing returns to scale of joint complementary inputs. We test the hypothesis using both size dummies (medium, medium-large and large firms[21]) and the number of employee (including linear and squared terms). It is worth noting that in local production systems innovation may mainly be spurred by medium firms, rather than by largest firms (Antonioli et al., 2004). As controls, we alternatively use the log of size (SIZE) and two dummies, for firms between 100 and 500 employees (MED) and with more than 500 employees (LARGE)[22].

(2) *Firm performances positively affect innovation.* Including both size and performances we control for eventual omission of relevant variables. Exploiting data about investments per employee, value added per employee (index of productivity) and gross profit/turnover we check which lagged performances element is acting as a determinant for innovation (Cohen et al., 1997). The sign of the relationship is difficultly assessable ex ante. This is a very general statement which also concerns non environmental technological and organizational innovation (Antonioli et al., 2004). 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. It is highly worth noting that both official datasets on firm performances (1995-2001) and subjective elicited data on performance trends (1998-2001) are available[23]. We use as performance indicators the average level (in logs) of two "performance periods", 1995-2000 and 1998-2000, in order to test

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[20] We specify in brackets acronyms used when presenting regression results.

[21] According to the Italian scenario, mainly characterised by local production systems grounding primarily on small/medium firms (firms with less than 100 employees here represent almost half of firms), we define medium firms those from 100 to 499 employees and large with more than 500 employees. Although the Italian system has performed well in the past, exploiting the innovative capacity and dynamism of small-medium firms operating in local systems and networks, a current key issue is revolving around the capacity of such a system to cope with the new challenges of global competitive markets, by introducing new value added processes and quality products, thus responding with new high-performance oriented techno-organizational investments, rather than acting defensively (i.e. labour cost reduction).

[22] Even some north-American studies define firms with more than 500 employees as "large-sized" (Gu and Tang, 2004).

[23] For transparency, official data are not available for 22 out of 140 firms. We fill missing values by substituting performances of firms belonging to the same sector and size.

diverse lagged effects (dropping year 2001)[24]. Acronyms are PROF, PROD, INV_N, indicating the time span of reference (i.e. $PROF_{95\text{-}00}$). Given the observed high correlation between productivity and both profits and investments, the PROD index is introduced *alternatively* to indexes PROF and INV_N.

(3) Policy actions affect innovation. No official data exist at micro-fir level, thus survey data is the only available option. Given the limited experience with market based instruments which are not widespread in the Italian environment, we cannot verify the different effectiveness of market and non market instruments in stimulating innovation[25] (Kemp, 1997)[26]. Having elicited whether emission and waste policies are being imposed to firms ("stringency" proxy), and for how many years firms have been subject to policies, we may want to analyse the eventual impact of policy indicators. In addition, we follow a conceptual reasoning which the assumption that environmental policy success depends mainly on specifici instruments; more important elements of successful policy are the stringency and the timing/duration of policies. We here use dummy variables for policy-regulatory pressures for emissions and waste (POL-EM, POL-WA) and the (log) number of years since the policy was introduced (POL-YRS), to test an eventual lagged/dynamic response of firms to environmental regulations introduced in a given year in the past. In fact, the disappointing results of some model-based policy evaluation are explained by the fact that implementation of policies requires time and the formal representation of lags is difficult. In general, there is a "policy cycle" - from first proposals to adoption, implementation, and reactions by involved actors, etc. - that has a great importance for effectiveness and its evaluation. Model based analysis of policy cycles can be difficult unless there are favorable conditions, in particular a long-enough time of application, enough available data, known factors allowing to represent the main the way policy affected the system. One would expect a positive sign on the proxy of policy stringency/presence, while no clear hypothesis is associable to the number of years: on the one hand firms experiencing policies for a longer time may show higher innovative effort as result of a long-run dynamic effect, on the other hand a shorter policy experience may also present innovative effort since (i) some firms react promptly to new policy targets to comply with them and (ii) newer firms, intrinsically experiencing policies by less years, could present higher innovative efforts with respect to new areas like environmental issues.

Another candidate variable for representing policy action can be direct and induced cost for policy implementation. Expenses seem to be a proxy for "costs", and most authors use environmental expenditures as a proxy for "policy stringency" (Brunnermeier and Cohen, 2003; Jaffe and Palmer, 1997). However, expenses and costs show different perspectives: expenses are closer to private and public investments, thus representing a close and instrumental consequence of policy action. Instead, costs are referring to all figures of direct, indirect and shadow costs (opportunity costs)

[24] Overall, gross profits/turnover indexes are lower, productivity slightly higher and investments per employee much higher, when considering only 1998-2000.

[25] The history of Italian environmental policy thus prevents us from analysing the different impact on innovation of market/non market tools and different market instruments (see Requate and Unold, 2003, for a theoretical assessment and ranking of the economic instrument effectiveness in providing innovation stimulus).

[26] See Hemmelskamp (1997) and Hemmelskamp and Leone (1998) for insights and evidence of policy effects on innovation concerning the European environment.

associated to policy implementation and compliance with the policy, by both private agents and eventually by society as large (if social market and non-market costs are also accounted for). Therefore, costs can also be accounted for as a part for the "achievements" of the policy (although with a possible negative sign) that parallel other achievements on the environmental side. Expenses may also be used with some caution in cost-effectiveness analysis of regulation/policy, provided the different units show the same level of performance indicator. Otherwise, the assessment is just possible on the basis of an examination of the effort specifically devoted to the environmental program under scrutiny. No efficiency consideration is instead plausible. What costs to include may represent a final controversial point, which is to be investigated case by case. Financial costs, current and capital expenses, indirect costs, external costs, opportunity costs are all possible candidates to enter ex post evaluations. We elicited information on direct environmental costs linked to current expenses, and financial burdens deriving from policies in order to take into account the aforementioned cost-related effect (ENV_COST).

Another side of the coin, which we may investigate depending on the future availability on productivity data, is the hypothesis on eventual negative/positive effects of environmental policy on firm competitiveness, which connects to the Porter idea at a micro-level.

(4) *Public grants for investing in more environmentally efficient technologies influence innovation dynamics*. We also test whether firms that have received environmental grants (GRANT) for innovation related investments from governmental bodies, exploiting specific Bills, are more likely to adopt innovation (although the number of firms receiving such grants is here low). Subsidies may be justified given the two market failures, environmental externalities and the public good nature of new knowledge (Popp, 2004)[27]. As a result, government subsidies and grants for less polluting technologies oriented R&D are often proposed as part of the policy package. It is worth noting that firms in our dataset do not exploit the existing Italian grants (only 5% do). This may derive from high administrative costs, informative costs, or from high opportunity costs to R&D. In a district based environment, nevertheless, networking activities involving joint efforts toward R&D and innovation may totally or partially substitute for top down governmental policy through subsidies[28]. This is a hypothesis we here investigate, though firms involved are just 5%.

(5) *Environmental R&D and capital investments are (positively) related to environmental innovation*. This hypothesis somehow relates to the Porter idea (Jaffe et al., 1995, 2002). At least in the long run, higher costs associated to environmental regulations should bring about, through innovation dynamics, a competitive advantage to firms which invest for enhancing the efficiency of production processes. More generally, R&D is recognised as an important innovation measure and an input for innovation output dynamics (technology invention and adoption) and firm productivity in a second stage. It is also observed that R&D may be an imperfect measure, since not all R&D

[27] See Montero (2002) for a theoretical analysis concerning the extent to which firm incentives to invest in environmental R&D depend on market structure given the presence of market strategic factors.

[28] Although environments characterised by network externalities and uncertainty, it may be cost effective to target grants instead of subsiding industry indiscriminately (Moretto and Dosi, 2004). Grants could then favour the achievement of a socially optimal level of spontaneous environmental innovation.

effort generates innovative output; empirical evidence on the R&D→ innovation → productivity links is not conclusive and is though to be sector-dependant.

We include R&D and investments (R&D, ENV_INV) as covariates separately given the (expected) high correlation between them[29]. Econometrically speaking, R&D, investments and environmental costs will be usually included as covariates once at a time, in order to capture their effect and avoiding collinearity problems (correlations between such variables are in a range 0,30-0,50). Both continuous and binary indexes (equal to one for positive values) of R&D/investments will be tested. Accordingly, log transformations are prevented given the (majority) of zero values (mean values in tab.3).

(6) *Eco-Auditing schemes (AUDIT) are positively correlated to environmental innovation*. We include auditing schemes for testing whether voluntary approaches (like EMAS, ISO14000) of environmental management improve, acting as driver, the likelihood of introducing environmental related innovation (acronyms are EMAS, ISO). Unlike ISO schemes, EMAS requires external communication via an environmental report. We also test the correlation between auditing schemes, which may be defined as part of the environmental organisational innovation strategy of a firm (Rennings et al., 2003), and process/product environmental innovations, by a bivariate probit model[30]. On the link between environmental innovation and auditing schemes we note the recent applied oriented contributions by Horbach (2003) and Frondel et al. (2004), who empirically verify the hypothesis of correlation between environmental process/product innovation and "environmental organisational innovation". Rennings et al. (2003) also analyse the interrelationship between various environmental related innovations, deeply focusing on EMS and associated green organisational corporate strategies innovative from an organisational point of view. Those papers provide preliminary evidence on the links between auditing, as part of a wider environmental organisational innovatory strategy, and environmental technological innovations, suggesting the need of further research on a complex and new issue. From a pure theoretical standpoint, Dosi and Moretto (2001) suggest that eco-labeling, which should enable firms to reap the consumer surplus linked to environmental attributes by identifying "green" products, may induce also perverse effects, such as increased investments in conventional technologies (more polluting with respect to new technologies) before the label is awarded. The effect stems from the existence of a complementarity relationship between polluting and green production lines, added to the award of labels for a subset of production lines, and not concerning all production activities.

(7) *Industrial relations play a role in favouring innovation*. The sign of the relationship cannot be defined ex ante. The mere presence of trade unions is not leading to higher innovative capacity. Different schools of thought tend to see in the presence of unions at the firm level a danger for the

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[29] We also estimate a regression using R&D and investments as dependant variables, and then we include predicted values as covariates in order to cope with endogeneity.

[30] In brief, the bivariate probit is employed when one wants to test the hypothesis of inter-relationship between two key variables. In other words, under the null hypothesis that the covariance between the error terms of the two distinct regressions is zero, the bivariate probit consists of two independent regressions. If the null hypothesis is rejected, we face a joint co-determination of the two investigated variables. In statistical terms, the errors of the two equations are related (a part of the errors term is common to both). For issues on the bi-probit analysis, see also the recent paper by Ferrer-i-Carbonell and Van den Bergh (2004).

efficiency of production processes, or an element of stimulus, pressure, and active interaction with the management. At the empirical level, contrasting results have been reached about the role of unions (Fernie and Metcalf 1995; Addison and Belfield, 2001) and their generalisation would not be granted[31]. The quality of industrial relations, concerning the interactions between management and both union delegates and employees, are strongly associated with techno-organisational innovations of any kind. Firms aiming at initiating innovative paths introduce policies favouring employee participation at the operative, organisational and macro-organisational level. At the same time, they also implement information flows, consultation and negotiation procedures with worker representatives on work organizations, process and product innovations. In the enquired firms, the quality of industrial relations emerges as a key factor supporting techno-organisational innovations and human resources management practices, first and foremost in the areas requiring or allowing worker participation and influence. Within the economic literature this "industrial relations driver" model opposes to the "management driver" model, and roots on procedures of consultation and handing over of decisional functions, from management to employees. This involvement is activated through the implementation of working groups with operative tasks, and joint commissions by managers, employees and union representatives, which aim at decentralising decisional processes. Union representatives are co-involved for reducing the risks associated to action coordination at a decentralised. This approach may be particularly effective when the aim is to reshape a fordist-taylorist structure.

The local production system under investigation is historically highly unionised. Industrial relations quality, in terms of co-operative relationships between management and unions and management and employees, matters for organisational and technological innovation (Antonioli et al, 2004; Mazzanti et al., 2005). We use a vector of synthetic index capturing the quality of industrial relations and unions/employee involvement in management strategies in order to test this link for environmental innovation[32]. To our knowledge the link between industrial relations and environmental innovation strategies has very rarely been tested[33].

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[31] Valenduc (2001) deals with trade unions as agents of environmental awareness. He stresses, proving anecdotal examples, that the sensitivity to environmental issues is very variable from a branch union to another. Even if there is a long-standing interest of trade unions in taking into account health, safety and environmental issues, it is not always possible to affirm that this is a highest priority. Environmental issues may be either a supplementary tool in order to improve other main areas of bargaining and negotiations (environment is a new dimension), or a specific goal, a new strategic priority, with trade unions acting as stakeholder in environmental policy at regional and local level.

[32] Our indicators of industrial relations, ranging between 0 and 1 to represent intensity and quality of management/trade unions/employee relationships concerning firm strategies, are: (i) an index capturing management initiatives vs. employees in work organizations (MAN-vs-EMP), (ii) a dummy capturing workers/unions participation at decisional firm levels (PART) (iii) a synthetic index of employee involvement in decisions concerning organizational innovation management (INVOL) (iv) a synthetic index of industrial relations intensity concerning high performance practices (IND-REL). The latter is a comprehensive index enclosing various aspects of the interactions between social parties; it takes into consideration the organisation of mangers/workers joint work groups, employee participation in formal structures with decisional power, etc... In essence, it attempts to capture all "innovative oriented" elements of social parties involvement.

[33] Frondel et al. (2003) provide some evidence on the effect of unions as a "pressure group", finding ambiguous evidence. It seems that on a descriptive basis management employees and corporate headquarters are influential in driving firm environmental strategies, although econometric evidence is weak. See Valenduc

(8) *Complementarity between organisational/technological innovation and environmental innovation*. Exploiting trends for high-performance practices/organisational innovation and process/product innovation in 1998-2001, we test whether environmental innovation is, following possible complementarities relationships[34], positively associated with other innovations. The most recent literature emphasises that the mere introduction of new technologies, without organisational innovation and new human resource management practices, dose not seem to support better performances. Bundles of high-performance practices are needed (Arnal et al, 2001, OECD, 1998; Janod and Saint-Martin, 2004[35]). The link between techno-organisational innovation and environmental innovation has never been tested to our knowledge. We use diverse proxies: a total index of organisational innovation practices (INNO_ORG), a dummy for Total quality management (TQM), a synthetic index of technological innovation (INNO_TEC) and a dummy for process innovation (INNO_PROC)[36]. As training is often considered a high-performance practice linked to organisational innovations (Huselid and Becker, 1996), and innovation-oriented input[37] we include among the set of possible covariates a training dummy (the firm adopts any formal or informal training practice, TRAIN) and an index of formal training employee coverage (COV). Training and/or skilled workforce measures are often hypothesised as complementary to R&D innovative input investments, for increasing firm performances. Finally, another proxy of organisational innovation is the flatness of the organisational structure[38]: it has been argued that flatter organizations perform better in terms of innovative dynamics, compared to Fordist-Taylorist more "centralized" firms (Aoki and Dore, 1994; Womak et al., 1990). Flatter firms should also move easier towards innovation

(2001) for some conceptual insights on the role of trade unions in environmental firm management and performance.

[34] 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 lead, 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). Substitution dominates under this perspective (Jaffe et al., 2002).

[35] This paper provides evidence on the impact of organizational innovation/change on a set of firm performances. The complementarity between techno and organizational changes, and between various forms of organizational change, is highlighted. The larger the number (authors stress "a sufficient number of additional practices", which clearly testifies that a formalised theory of reference is hardly achievable on this matter) of changes occurring at firm level, the more likely that complementarities (see Milgrom and Roberts, 1990) play a role in improving performances. Within the environmental economics arena, we are not aware of any evidence on neither the effect of environmental innovation, in a jointly way, on firm performances, nor of the impact on environmental innovations of different techno-organizational changes. The field is clearly one where research is needed to build up some empirical evidence.

[36] Training efforts may be included among high-performance practices as well as organisational innovations. Although correlation between different practices is often quite high, and the present case confirms this hypothesis (Guidetti and Mazzanti, 2005), we also test the relevancy, as separate driving factor, of training (TRAIN), using as indicator the percentage of employees involved in any training practices. Given the observed correlations around 0,30 on average (medium-high), covariates concerning industrial relations, organizational innovations and training will be carefully introduced separately as driving forces.

[37] Ballot et al. (2001) and Gu and tang (2004) provide diverse empirical evidence on the hypothesis that R&D and training, and R&D and skilled labour force are among the innovation oriented drivers of manufacturing firm productivity.

[38] The EC (1997) has underlined the role of changes in firm organisation in developed countries. An evolutionary process characterised by the transformation of the Fordist-Taylorist organisation has taken place over last decades. Firms can be described as learning organisations, characterised by a flat and decentralised structure (Lundvall and Nielsen, 2002). Organisational decentralisation is often linked to forms of decisional decentralisation.

flexibility dynamics rather than defensive strategies (labour cost reduction, labour saving technological process). Within the specific realm of environmental innovation such hypothesis, which involves a complex reasoning over human resources, innovation and organisational strategies, is never been tested. We capture the element by an index of hierarchical levels on establishment business "functions" (hierarchy ratio): the lower the index, the flatter the firm (HYER). The hierarchical intensity is not particularly high in the local system: there is a tendency to increase the number of formalized functions without strengthening the pyramidal structure.

(9) *Networking activities are (positively) associated to environmental innovation (through environmental R&D).* This point deserves attention. The importance of networking relationships, in terms of voluntary agreements and spillovers is high in district industrial areas. Networking activities may partially substitute for size driven economies of scale in environment characterised by small and medium firms. We elicited data on the source of environmental innovation (internal to firms or external: by cooperation with other firms, by cooperation with research institutes, by acquiring innovations from other firms). We cannot obviously use here networking information for directly explaining innovation (Cappello and Faggian, 2005). We instead use it to test an important hypothesis which recently emerged from the "social capital (SC) literature" (Cainelli et al., 2005, Mancinelli and Mazzanti, 2004; Glaeser et al., 2002; Durlauf, 2004): the complementarity between R&D and social capital in an impure public good framework (Cornes and Sandler, 1997), where social capital arises as an intangible assets, defined as the sum of firm investments in co-operative/networking agreements, is the public good element.

The necessary joint effort to establish voluntary co-operative schemes, by which achieving goals specific to the network but appropriable by participants, characterises most forms of (i) voluntary agreements[39], (ii) inter-firms infra district cooperation, (iii) inter-firms inter-districts cooperation. The relevance of points (i)-(iii) as engines for innovation and growth at a regional level has increased over the last decades, following both the less prominent role of the state as 'regulator' (top down approach), and the reshaping of governance and business strategies within the post-fordist society. Actually socio-economic changes occurring in the post fordist (post-industrial) era shift the focus of interest from man made forms of capital to human, environmental and SC assets. Further, market and non-market 'horizontal' networks play a major role with respect to 'vertical' and hierarchical relationships, bringing about a new scenario described by a cultural change in local and National production. Finally, social capital/networking externalities might turn over standard Marshallian externalities in explaining growth and innovation processes. The community benefits from positive network externalities; nevertheless, differently from exogenous spillovers, the voluntary and intentional production of joint social benefits is costly; therefore incentives matter. Networking is nevertheless strictly connected to private components of welfare (it is not a pure 'independent' public good), to which is linked by some degree of complementarity relationship. We may intend the investment on the private form of capital as a BAU choice, and the investment on the impure

[39] See Aggeri (1999) for a conceptual analysis on the role of voluntary agreements in the realm of environmental policy.

public good as network specific R&D generating radical innovations. As an example, the reader may refer to the usual situation characterised by the formation and development of voluntary agreements among firms, within a district or along a productive chain, aimed at reaching environmental long run and policy-driven targets, for which existing knowledge and technology embodied in BAU capital are not sufficient[40]. We thus use "networking" dummies (cooperation with other firms and cooperation with research institutes in developing innovations for the four identified innovation areas, from emissions to energy: acronyms are NET-suffix) as explanatory variable of R&D in the innovation input regression. We also construct a total networking index ranging from 0 to 1, synthesising the four dummies (NET-TOT): this represents the networking innovation oriented involvement of firms with other firms and research institutes across environmental realms. To our knowledge the link between environmental-oriented networking strategies (Aggeri, 1999; Aggeri and Hatchuel, 1997) and R&D has never been tested for environmental innovation[41]. Finally, it is worth noting that potential endogeneity may affect the networking-related variables. According to some contributions on industrial districts (Brusco et al., 1996; Cainelli and Zoboli, 2004), his kind of formal and informal networking relationships may be interpreted as a quasi-fixed factor of 'production'. In any case slow evolving over time, thus pre-determined exogenous factors with respect to firm innovative efforts.

(10) Finally, it is worth noting that the set of covariates also include additional control variables which may act as explanatory factors of innovation[42]. Following the literature on firm innovation, we include the share of revenue in international markets (INT_REV), the share of final market production, complement to subcontracting production (FIN-MKT), the firm sector, using a set of dummies for Machineries (MACH), ceramics (CER) and chemicals (CHEM). Other less innovative and more importantly less environmentally strategic/critical (in terms of polluting outflows) sectors identify the base case. Those dummies also captures a "district agglomeration effect", as associated to the machineries and ceramic local district agglomerates. Finally, a dummy capturing the membership to national or international industrial groups is also used as control (GROUP).

4.2 Methodological issues and innovation modelling

There is no shared theoretical model for studying innovation determinants both at industry and firm level. In effect it is very difficult to specify a theoretically satisfying structural or reduced form equation for both input and output innovation (Jaffe and Palmer, 1997), as, for instance, a

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[40] In this sense, SC as a stock captures the idea that collective external economies of scale are realised by cooperation over input activities, such as research, technological development, organisational innovation, and training and advertising, wherein fixed costs are pooled among agents who join (Caloghirou *et al.*, 2003).

[41] See Negassi (2004) and Cassiman and Veugelers (2002) for recent contributions investigating the link between networking/information spillovers and innovation dynamics.

[42] Schmultzer (2001) notes that the policy stimulus is not sufficient in many cases, and highlights the potential stronger role of drivers associated to firm structural variables, and (we add) external structural factors such as networking. Regulatory intensity and typology, technological factors, market dynamics and firm structure are all potential determinant of environmental innovations. The point is crucial for environmental policy actions, which has so far mainly focussed on a circumscribed environmental-only arena: if firm structural variables and external relationships arise determinant, the relevant policy package is composed of environmental policy, industrial regional policy and local policies favouring bottom down networking. The scope of environmental policy widens and interrelates with other realms.

"production function" approach. In addition, the set of potential explanatory variables is large, ranging from firm structural characteristics and firm performances, to exogenous factors, like policies, to organisational and technological dynamics, belonging both to the specific environmental arena and to other strategic business areas which nevertheless may exert indirect influence on environmental innovations. One aim of the paper is the attempt to extend the usual core of driving forces which is often restricted to environmental-related factors and some control elements. At a conceptual level, we here extend the usual linear innovative process, which mainly link innovation to R&D as input, toward a multidimensional set of inputs which is definable as a "broad production factors". This approach is even more necessary in the realm of environmental innovation. The full set of drivers is investigated.

The analysis is forced to rely on quite rough reduced forms, specifying the proper econometric model for each continuous/discrete variable under analysis. The "pillars" giving robustness to the study, in absence of a theoretically based reduced form, are sample representativeness, the quality and quantity of firm level data, and the way we cope with endogeneity.

Before starting the regression analysis, a preliminary selection must be carried out for studying the full correlation matrix concerning potential covariates, dropping high-correlated potential regressors (correlation values for regressors are shown in tab.3[43]). This first selection is aimed at reducing collinearity problems, selecting the set of covariates for testing each specific hypothesis. The initial matrix of pre-selected explanatory factors actually presented limited problems concerning correlations. This is a good factor for applied analysis. The only critical points concern the relationships between industrial relations, and high-performance practices, quite highly positively correlated, and some performance indexes. Besides those indexes, which will be consequentially cautiously introduced, the correlation matrix generally shows low figures concerning main independent variables. Then, a "from general to particular" backward stepwise method is applied, which may result more consistent with the different biases arising when variables relevant variables are omitted or irrelevant ones are included: in the former case coefficient are biased, in the second case variances are inflated by using too much information and estimates are less efficient. Thus, the second problem, over fitting specifications starting from a conceptual model, is less severe and can be resolved by eventually deleting non-significant variables (i.e. t ratios less than 1,282 step by step). Further, it is worth noting that the omitted variables issue is one of the main causes of endogeneity (correlation between explanatory variables and errors), often due to data unavailability (Woolridge, 2002, p.50-51).

Econometric analysis focuses on (a) estimation of the determinants for specific environmental innovation (emission-related, waste-related, and energy related); (b) estimation for a synthetic index of innovations (c) estimation of regression for R&D and investments relating to environmental innovation. Ina addition, a bivariate probit analysis is used to test the correlation between various environmental strategies, for instance, between auditing schemes and innovation tout court.

[43] Among all covariates presented in the table, 4 correlations show values higher than 0,50 (in absolute value), 5 higher than 0,40 and 14 higher than 0,30. high correlations pertain to clusters of conceptually similar covariates, which are then introduced one at a time in regressions.

(a) Innovation output for specific innovations

In order to perform this exercise, we estimate a sort of 'knowledge production function' (Griliches, 1979). The knowledge production function expresses the relationship between innovation output and innovation inputs within the 'conceptual' framework[44] of a production function. The reduced form is as it follows:

$$(1)\quad INN_{i,t} = {}_{0} + {}_{1,t}(\textit{structural firm features}^{45}) + {}_{2,t/t-1}(\textit{environmental policy}) + {}_{3,t}(\textit{environmental R\&D}) + {}_{4,t}(\textit{environmental grants}) + {}_{5,t}(\textit{environmental direct costs}) + {}_{6,t-1}(\textit{techno-organisational innovation}) + {}_{7,t-1}(\textit{industrial relations}) + {}_{8,t-1}(\textit{performances}) + e_{i}$$

where INN_i represents the environmental innovation output of firm i, and e_i the error term with usual properties. ${}_{0}$ is the constant term, ${}_{1\text{-}8}$ the set of coefficients, where (t) stays for 2003-2001 and (t-1) for 2001-1998.

Econometrically speaking, this *knowledge production function* is estimated by means of a Logit/probit specification.

From the econometric point of view, the estimation poses at least two problems. First, heteroskedasticity, as it is often found when cross sectional data are used, may reduce the efficiency of econometric estimates. Thus, all estimates are carried out adopting a 'robust' estimator which addresses such source of distortion. Secondly, there is a potential endogeneity when investigating the determinants of innovation[46]. Panel dataset may be a better framework. Nevertheless, the nature of techno-organisational innovation, intangible assets, networking and policy-related data, all potential drivers of innovations, often prevent the setting up of proper panel dataset given most factors are definable quasi-fixed or slow evolving (Huselid, 1996; Brynolffson et al., 2002). A way to deal with the problem is by introducing a vector of 'lagged' term into the regression[47] (thus specifying an hybrid cross sectional model) for all relevant covariates. Most of our drivers are temporally preceding innovations (2001-2003). For R&D, we use both the effective elicited 2001-2003 value and the predicted values stemming from a first stage R&D regression, in order to cope with endogeneity (or, better, temporal coincidence of the two data, both for 2001-2003) between R&D and innovation. Though the direction of causality is not ambiguous in this case (from R&D to innovation), the use of a two stage procedure helps making estimates more robust.

(b) *Synthetic index of Innovation output*

When estimating the total innovation index, ranging between 0 and 1, we face a limited but continuous variable. We deal with *fractional variables* (Papke and Woolridge, 1996), continuous but limited. It is possible to affirm, building up on the empirical contributions which have dealt with the

[44] Even without assuming the usual neo-classical properties concerning production inputs.
[45] Size, market features (national market share, subcontracting share), sector, district membership, etc...
[46] See Huselid and Becker (1996) and Cassiman and Veugelers (2002) for more insights on the issue.
[47] For transparency, we note that one overlapping year is present (2001) when regressing information about innovation (2001-2004) on the set of covariates which concerns 1998-2001 (and performances over 1995-2000).

issue (see, among the others, Antonioli et al., 2004; Mazzanti et al., 2005; Fronstin and Holtmann, 1994), and on the empirical contributions specifically concerning training (quoted above), that there is not an "optimal" econometric model for studying fractional variables. Although OLS estimates may suffer from the same distortions characterising the use of linear models for binary variables, the often used one limit or two-limits Tobit models (Rosett and Nelson, 1975; Tobin, 1958) are not a panacea, and often it is possible to verify that estimates deriving from OLS, OLS based on (log) transformations and Tobits do not differ significantly as far as coefficient signs and "relative" statistical significances are concerned (Pindyck and Rubinfeld, 1991), although OLS generally lead to different coefficient "levels". Since the aim is not (here) the estimation of elasticity, this may be considered a less severe flaw. Thus OLS corrected for heteroskedasticity is used as econometric tool for estimation.

(c) *R&D Innovation input*

R&D per employee. We estimate a simple reduced form equation for R&D investments per employee (Jaffe and Palmer, 1997). The log value is often used as dependant variable. Nevertheless, environmental R&D is not positive for many firms, which report a zero corner value. This is plausible with other evidence (Horbach, 2003). Thus, R&D equations are first estimated by means of OLS corrected for heteroskedasticity: OLS is nevertheless generally inconsistent when facing "corner solution models", both using the entire sample and a subset of it. Those models arise when y takes on the value zero with positive probability but it is a roughly continuous random variable over positive values. As discussed in length by Woolridge (2002, ch.16-17), those models are often wrongly labeled censored regressions, though the issue is not data observability as in censoring and truncation (i.e. the difference is maybe subtle, but a comparison of wage equations of labour supply and R&D equations may give a hint of the difference)[48]. Corners solutions models refer to a hypothetical economic model where the zero value is the "optimal", and observed, corner solution for most agents. As a consequence, more appropriate Tobit (Type I Tobit model, following Amemya's definition) and two stage heckit/two-tiered models are then used. Alternatively to OLS, a probit model specifying as "1" firms with positive R&D is also tested[49].

4.3 Econometric results

We present and comment results for the set of hypothesis formulated above. Different regressions are investigated (tab.4a-b). We examine various environmental-related output innovation equations (5), environmental R&D equations and a series of bivariate probits on environmental innovation and

[48] Following Woolridge (2002) the "family" of censoring-like models may be subdivided in various different models: models with intentionally exclusion of part of the population (truncated regression), censoring models with incidental truncation, corner solution models where zeros are not stemming from data observability problems or sample selection. Most econometric books define the two latter ones "censoring" opposed to truncation models. The limit/corner value may nevertheless represent different economic situations and statistical meanings, which mainly revolve around the observability issue and the underling economic model (i.e. wage supply vs R&D expenditures). Functional transformations, Tobit, two stage procedures are statistical structures for addressing censoring like models.

[49] Connecting to the issue of fractional variables, corner solutions model may also be addressed by specifying a functional form that ensure that E(y/x) is positive for all values, like the exponential, then using non linear least squares. The procedure has nevertheless its limitations (Woolridge, 2002).

environmental management (not presented for brevity; only bivariate probit correlation values are shown)[50].

For output innovations, given that data presents simultaneity of innovations, R&D, environmental costs and auditing schemes (all defined as trends over 2001-2003), potential endogeneity should be tested, though, as we remarked above (par. 4.2): (i) emphasis is on trends; this is plausible given the slow-evolving nature of such variables. (ii) The causality nexus is clear in this case, if compared to the innovation-performance link, intrinsically subject to the reverse causality conceptual problem. In fact, R&D is an input, costs are an input and partially policy-driven, auditing schemes may be correlated to but hardly "explained" by innovations. Nevertheless, endogeneity is properly checked by implementing a Wu-Hausman test (Woolridge, 2002, p.118-20), which is a regression-based form of the Hausman test: fitted residuals or predictions estimated from a first stage regression using *all* instruments for the potential endogenous variable (x) are used as covariate in a regression of y on x and all the previous used instrument, including a constant (remember that all exogenous variables are used as instruments for themselves). The usual t test statistic on the targeted variable is a valid test of endogeneity. In other words, if the "object" variable is not significant we may assume its exogenity and IV estimation is not needed. In our case, a significant coefficient emerges only for environmental costs in some of the regressions, and never for R&D and auditing. The outcome confirms ex ante expectations, since costs were, relatively speaking, the most likely factor to present endogeneity problems. We then introduce in those cases the associated fitted values as a further estimation option in this case[51]. We note that standard errors deriving from two-stage procedures have a tendency to be rather large, larger than OLS. This depends on the quality of instruments used. Thus, often we should manage a trade off between possibly inconsistent OLS coefficients with relatively small standard errors and a consistent but imprecise estimator. The problem is harsher in relatively small datasets; since the Wu-Hausman tests preliminary carried out highlight potential endogeneity for costs only, this issue is only partially touching our frame of analysis.

Further, R&D and costs are introduced both separately and jointly as explanatory variables, to check whether their positive correlation may lead to distortions in estimates.

4.3.1 Input innovations

[50] Acronyms for the various dependant variables are: INNO-EM (adoption of process/product environmental innovation related to emissions), INNO-WA (adoption of process/product environmental innovation related to waste), INNO-EN (adoption of process/product environmental innovation related to energy inputs), and INNO (adoption of any environmental innovation). Those five are dummies. We do not exploit firms that adopted all four innovations since the number (12) is too limited. Then, we have INNO-TOT (synthetic index of all resource efficiency environmental innovation), and environmental R&D (R&D).

[51] See Woolridge (2002, pp.90-93) for a comprehensive discussion on "two-stage least squares". He notes that the first stage regression producing the fitted values must contain all instruments for x and all exogenous variables then included in the second stage regression. Otherwise, inconsistent estimators of relevant coefficients may arise. A further note: given our innovation proxies are in some cases binary variables, we refer to Woolridge (2002, p.474-5) for the 2SLS procedure in probit analysis, which is still one of the ways to cope with potential endogeneity on a continuous explanatory variable.

We begin commenting the outcomes for the *input innovation* equations, for R&D and environmental investments, following a logical consequential reasoning starting from input and then moving to innovation outputs.

Concerning both input proxies, two analyses are attempted: one using the log-value per employee as dependant variable in a "corner solution/censoring model" and the other, given the high number of "zero", using a probit model where positive values are associated to one. In the first case (continuous R&D variable), Tobit and two-stage procedures are used as estimation tools.

Probit analysis on environmental R&D shows the following outcome. Ceramic and chemical sectoral effects are the only structural features associated to the firm which result to significantly drive R&D. Size-related effect do not emerge. In addition, the share of final market production tends to positively explain the amount of resources devoted to R&D. Other firm related factors affect R&D, all with a positive sign: the quality of industrial relations within the firm (proxied by the index IND-REL, which derive from information on the trade unions involvement in internal labour markets, organisational practices, and participative / consultation processes), the number of hierarchical levels (which represent a proxy of "organisational flatness", read in the opposite way), and to a lesser extent organisational innovation (number of innovative organisational practices). The positive sign attached to the number of hierarchical levels poses a problem: in fact innovative dynamics are often more likely to be positively correlated to flat organisational structures[52] (see below for opposite results on innovation output indexes)[53].

It is worth noting that the covariate capturing the firm involvement in operative and networking activities specifically devoted to environmental innovation (NET-TOT) exerts a positive effect on R&D, though significant only at 10% level (quite close to the 5% threshold). The index concerning the total networking effect across all environmental innovation realms actually hides possible different links: in fact only networking for emission-related innovation arises highly significant if indexes are separately introduced. All in all, networking effects turn over size effects, highlighting a theoretically defined complementarity between R&D and networking investments as "inputs" of innovative outputs.

Among policy drivers, the dummy concerning emission policies is the only significant driver, and reduces the t value attached to networking when included. Auditing schemes and grants do not affect the probability of R&D being positive. Training activities, which are often claimed to be associated to R&D for high-performance and more innovative firms, never show to be significant, as well as organizational practices.

When specifying R&D/employees as dependant variable, we note that the OLS estimates perform poorly in terms of overall regression fit and coefficient robustness. The censored nature of the

[52] See Aoki and Dore (1994) and Womak et al. (1990). Most authors stress the innovative properties of flat organisations. Nevertheless, though this is a shared and plausible hypothesis, other elements should be taken into account. The role of flatness as driving force for innovation may vary by sector, for instance.

[53] The analysis of correlations confirms the opposite signs: while is (weakly) negatively correlated to all innovation proxies, the ratio index of hierarchical levels/firm functions is more significantly and positively related to R&D and investments.

variable may be the underlying reason. We thus adopt a Tobit model which is more consistent with a R&D censored distribution having a significant bulk of zero observations.

Tobit results (not reported) slightly less robust than probit[54], are: the networking effect increases its significance level, although within a 10% statistical threshold. Among sector and size dummies, only the chemical industry seems to positively influence R&D. R&D is also positively correlated to past productivity. We also attempted to use only firms with positive R&D values (61 units out of 140). The outcome is not statistically satisfactorily; the reason could be that discarding limit observations leads to a truncated regression setting, "which is no more amenable to least squares than the censored data models" (Greene, 2000, p.908).

As a final analysis, we use a two stage procedure (hurdle model), finding no evidence of a two-tier process (last column tab.4b). The model fit is nevertheless good. Networking, organisational factors (flatness), industrial relations elements and productivity performances affect R&D as shown in tab.4b. A positive role of training (COV) also emerges, though the coefficient significance depends on the inclusion of other positively correlated "high-performance" practices and industrial relation proxies, thus is not robust. Auditing schemes do not matter. As far as networking is concerned, when dummies for specific environmental realms are included, it emerges that energy-related cooperation is the only and most significant, maybe driving the total networking effect. Summing up for networking, this preliminary evidence highlights the role of cooperation with other firms and research institutes, with specific evidence on emission and energy contexts. The regression including energy-related networking dummy is associated to higher fit measures.

4.3.2 Output Innovations

As far as *output Innovation* proxies are concerned, we observe the following outcomes deriving from binary probit analysis[55]. As a preliminary analysis, we focus on the INNO (**adoption of *any* environmental innovation**) index. Results (not shown) are not highly satisfactory in terms of fit, probably depending on the rough measure of environmental innovation (innovate/not innovate): analyses using more specific indexes is needed. Primary positive effects are associated to environmental investments (most significant), environmental costs and to the flatness of firm organisational structure (we remind this is a structural factor behind innovation dynamics, as shown

[54] Fin and Schmidt (1984, see Greene, 2000, p.915) point out that a problem with the Tobit is that a variable increasing the probability of an observation being a non limit observation also increases the mean of the variable. We test the restriction of the Tobit model: the Tobit log-likelihood is the sum of the log-likelihoods for the truncated and probit models. A LR test can be computed as a consequence. Concerning R&D, the hypothesis is rejected by data.

[55] As measures of goodness of fit, we report the value of the log-likelihood test comparing the maximised value of the log-L function and the log-L computed with only a constant term. Furthermore, an analogue of the R^2 in conventional regressions is McFadden likelihood index, which has an intuitive appeal since it is bounded by 0 and 1 (Greene, 2000, pp.831-833). The index increases as the fit improves, though values between 0 and 1 have no natural interpretation. The fit measure should possess the following properties: assuming a 0 value for absence of fit and 1 for a perfect fit; based on a robust statistical test for the hypothesis that all coefficients are not significant expect the constant. Other fit measures have been suggested by various authors (Greene, 2000, p.832). Among the others, we note the measure proposed by Estrella (1998), who propose a measure that takes into account the share of correct predictions (higher or lower than 0,5) on the basis of observed 0 and 1 values. Greene (2000) nevertheless points out that all in all it is important to place limited emphasis on diverse measures of goodness of fit when dealing with discrete dependant variable models.

by other contributions (Antonioli et al., 2004). High-participative innovation oriented industrial relations also positively influence the adoption of innovation. Size effects are not significant as well as past performances, while sector dummies arise (weakly) significant, with a dominant effect exerted only by machineries. All in all, policy drivers do not *directly* matter.

When disaggregating by "environmental issues", outcomes are the followings (tab.4a).

First, **environmental innovation concerning emission-reduction** shows to be positively influenced by the presence of voluntary auditing schemes. Concerning policy-related explanatory factors, we note that the presence of emission-specific policy is positively related to innovation; nevertheless, quite interestingly, the probability of adopting emission innovations is inversely proportional to the number of years the firm has been subject to the policy. This number of years, reported by firms themselves, may depend on historical, productive and institutional reasons. The outcome is somewhat counterintuitive and will be confirmed below: following this evidence it seems that policy effects are stronger in the first phase of policy implementation, fading away with time. The positive effect of R&D arises only when specifying a dummy variable as explanatory factor (R&D/employees instead is not significant, as well as environmental costs[56] and investments). Size and sectoral controls do not influence adoption. The index of "participative innovation oriented" industrial relations is a positive driver. Finally, firm performances do not matter.

Secondly, **waste-management related innovation** is primarily affected by policy proxies, as reported by firms. As above, we note in fact that while the "policy dummy" is positively significant, the probability of adopting waste management innovations is inversely related to the years of policy implementation. Although the number of firms exploiting grants is low, the factor is here significant. Then, policy effects may also pass through the positive influence of environmental costs, which are moderately significant[57]. Nevertheless, we note that though the Wu test highlighted potential endogeneity, even for waste the fitted values are not significant. Waste innovation also shows to be positively influenced by the presence of voluntary auditing schemes and by a flatter organisational structure. While size is still not significant, with Group membership turning over size effects, some sectoral influence emerges (Ceramic).

Third, turning to **innovation in the realm of energy efficiency**, we observe that R&D is significant among the endogenous firm drivers when included as dummy variable. In this case, investments are more significant in explaining energy innovations: this is plausible given the high technological fixed costs and the low relevancy of end of pipe solutions in these environmental realms. In addition, size effects are here more influential, although they do not emerge as strongly statistically significant. Industrial relations dynamics confirm their already noted positive effects. Finally, sectors do influence innovation: this may appear not surprising given the differences in energy intensity across manufacturing sub-sectors. Ceramic is the most significant driving sector.

[56] Predicted values of costs are included following the endogeneity test, but they do not arise significant.

[57] Some authors have stressed and provided evidence of a negligible cost of waste disposal, on average less than 1% of turnover. Nevertheless, the disposal (expected) costs have strongly increased over the very recent years, and most businesses now believe that waste minimization could save money, mainly by reducing material inputs (Martin and Scott, 2003; Gibson, 2001). The waste/material issue is one of the hottest, given no evidence exist of an inverted U-shape EKC curve for waste and material in general terms.

Finally, but not least important, we examine the 0-1 continuous **index capturing the four realms of innovation** (INNO-TOT). OLS corrected estimates show (tab.4a, last columns) that (i) R&D and costs are significant while investments are not (regression 4[58]); (ii) Policy drivers, like grants, in addition to policy driven environmental costs (which we may intend as a proxy of indirect effect of policy) are also significant[59]. Auditing schemes are significant (with EMAS dominating over ISO14000). Sectors and size do not influence the adoption of innovation measured in terms of "intensity". Scale economies emerge through the effect of "group membership". Finally, confirming an already mentioned evidence for specific realms, innovative activity is more intense in flatter organizations and in firms where the quality of industrial relations is good in terms of workers and unions participation to decisional processes on high-performance and organisational strategies. Performances confirm not to influence environmental innovation.

As a conclusive step of the applied investigation, the quantitative analysis on **innovations by bivariate probits** (tab.5) shows that: (i) concerning the hypothesis of correlation between environmental innovation and auditing voluntary schemes, correlation is strongly found in two cases (emission and waste); (ii) concerning different environmental innovations, correlations is significant in two cases (waste-emission, emission-energy), (iii) a significant correlation is found between R&D and investments.

4.3.3 Main outcomes

We sum up the main outcomes. As far as firm structural features are concerned, size effects are significant only when considering innovative inputs. All in all, the effects exerted by group membership and networking activities, two relational dynamics, here represent the "scale economy" driving forces, turning over pure size effects. This evidence is highly interesting even for policy purposes. Market features also do not matter. By sector, effects on innovation are not strong but more evident: the chemical and ceramic sector emerges as moderately important drivers in some cases.

Other firm characteristics instead influence the adoption of innovation more evidently: organisational flatness is generally emerging a driver of innovative output, and the variables concerning industrial relations, mainly the synthetic index IND-REL, exerts overall a positive influence on adoption. Though the correlation between size and this industrial relations index is not extremely high, the positive value may suggest that some size effects are better captured, in our estimates, by industrial relations dynamics occurring in medium-large firms. Nevertheless, more specific variables of employee involvement do not result significant. More research is needed on the role of trade unions and employee participation concerning environmental innovation dynamics.

Concerning Policy divers, direct and indirectly conceived, we find significant effects across regressions. Policy-related proxies are relevant for emission and waste policies, with a somewhat counterintuitive negative effect in relation to the "number of policy years" effect. Given that the

[58] This regression is eventually affected by the positive correlation between such drivers (around 0,35). R&D and costs are still significant when investments are omitted and the overall fit also improves (5,6).
[59] Even omitting grants, regressions keep overall and coefficient significances.

historical experience with environmental policy is in Italy relatively recent, further evidence is needed. Environmental costs (current expenses and policy related expenses) instead arise as a core driver for most innovative output specifications. Environmental grants are exploited by a very limited number of firms, thus their positive statistical effect is to be cautiously interpreted.

Turning back to R&D, we observe that it arises as a primary driver for most innovation output realms. It is interesting to note that networking activities with other firms and research institutes are a driver force of R&D and investments. There is some evidence in favor of a causal chain link like: networking/cooperation → R&D → innovations. This link emerges when focusing on the total index of innovation. More research is needed. It is worth noting that the assessment of relevant networking and spillover effect concerning R&D/induced innovation would justify the implementation of specific subsidies and/or even higher Pigovian taxes, with respect to the case of innovation dynamics which are completely internal to the firm (Rosendhal, 2004).

Overall, technological and organisational innovations and high performance practices, including training, seem not to be correlated to environmental innovation[60]. The hypothesis that firms adopting high performance practices and techno-organisational innovations also present higher innovation concerning environmental issues is here not validated. No link between R&D and training, as potential intangible complementary inputs, also arise. Nevertheless, the relative flatness of the firm seems to influence both more innovative environmental strategies and non environmental techno-organisational ones. Thus, though a direct link is not emerging, environmental and non environmental innovation realms may be driven by the same innovative-oriented structural dynamics (flatness, participatory schemes, and good industrial relations) characterizing the firm. Given the scarce evidence on this point, and the complexity of the relationship, further evidence is needed for achieving new and more robust insights.

Within the realm of "organisational innovations", a clear positive association is shown to exist between all output innovations and voluntary auditing schemes. When considering the total innovation index (INNOTOT), EMAS certification emerges as primary factor. This is consistent with the "incremental" nature of EMAS with respect to ISO14000 (though we note that EMAS-certified firms are currently not many).

Finally, we stress again that it is difficult to assess a clear ex ante theoretical hypothesis concerning the effect of firm performance on innovation. Past productivity may influence innovation in both negative and positive directions, while for profits we may expect a positive impact, although profit dynamics are, at least in the short run, "distant" from technological/innovation cycles. Evidence here suggests that performances (profits, productivity) do not constitute a driver for environmental innovation, if not in rare cases concerning productivity (but never significant). Overall, performances do not arise as primary drivers and their effects are dominated by the other explanatory variables. The performance effects, although not dominant, was found instead stronger for non environmental innovation typologies (Antonioli et al., 2004).

[60] Instead, training and techno/organisational innovations are positively correlated. This reinforces the present evidence: environmental innovation seems, accordingly to our data, disentangled from other innovation and high-performance practices, at least if we observe their direct relationship.

5. Concluding remarks and Policy implications

The paper provides new empirical evidence on the determinants of environmental-linked innovation at a microeconomic level. We exploit a recent and rich survey based datasets covering market and non market firm features. The focus is on local production system grounding on industrial districts, which is a quite unexplored case in the literature on environmental innovation. The paper adds new insights on the complex analysis concerning the driving forces of environmental performance at firm level, since it explicitly considers the relevancy of networking dynamics, techno-organizational innovations, environmental R&D and industrial relations, as long as the more usual policy-related and structural variables, among the potential driving forces of innovation in district-oriented industrial systems. The investigation has shown that environmental innovation drivers, at both input and output levels, are to be found within (i) exogenous factors, (ii) endogenous dynamics concerning the firm and its activities/strategies within and outside its boundaries, and (iii) both environmental and non environmental structural elements of the firm.

Empirical evidence has shown that policy drivers exert some effects on innovation, although results differ by innovation typologies. More effort is to be devoted to environmental grants, whose eventual effectiveness is undermined by the very low number of firms exploiting public funds. Voluntary eco-auditing schemes also appear to play a strong role in favoring innovation output dynamics, even more than input factors as R&D.

Firm size is never significant, while sectoral/district influence is somewhat positive, but impact is weaker with respect to other drivers. More than size, group membership and networking arise as positive innovative drivers, respectively for innovation output and R&D: this means that "horizontal economies of scale" and cooperative agreements/strategies might matter more than internal economies of scale, which are instead more relevant for non environmental techno-organizational innovation dynamics. Those latter are in fact not here correlated to environmental innovations and R&D, validating this statement. This evidence is new and it is possibly representing an added value for understanding innovation environmental dynamics and for orienting policy actions in local systems. Given the high percentage of small-medium sized firms (with less than 100 employees), this may represent good news for environmental performance of the local system: standard economies of scale are not a priority for the environment, although trade offs may emerge with other realms, since size appears relevant for techno-organizational innovation and high-performance practices like training. Another view would instead focus on the role of J-firm characteristic like a less hierarchical structure and a participatory environment in favoring the adoption of both environmental and non environmental innovations. This is the evidence arising from the industrial environment here analyzed. Trade offs could be mitigated under this perspective.

It is then highly important to investigate, for any innovation typology, what the drivers are in terms of "internal" structural firm features and external networking relationships. Our investigation suggests that networking relationships aimed at building up a social capital, instrumental to creating and introducing innovations, and "membership" to a district or a group, are factors as much as important, if not more, than firm structural characteristics.

It is worth noting that a three-factor link might emerge: networking "investments" and research-oriented relationships are possibly influencing (and theoretically being complementary to) R&D/environmental investments. Then, and consequently, R&D is one of the inputs driving the adoption of innovative output. Further applied research is suggested on this key new topic to provide some generalization.

Summing up, the "innovative driver box" may consist of the following main factors: (i) firm involvement in groups and networking activities, (ii) "innovative oriented" industrial relations and a less hierarchical organization. These driving factors contribute to drive environmental innovations, together with environmental (policy related) costs, R&D and, final but not less important, voluntary environmental schemes. External-oriented firm behavior, environmental specific R&D, the reshaping of organization structures and management-employees relationships along more flexible and innovative scenarios, and policy-related elements all may induce innovations impacting firm strategies and firm behavior. Although specific to districts and to the industrial system here studied, our results may represent a first attempt to assess a comprehensive framework of innovation drivers in the environmental arena. The analysis also opens some new research directions, widening the vector of potential driving forces of environmental innovation when dealing with complex and evolving industrial systems.

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Tab.1a: Total firm population

Sector	no. of employees						
	50-99	100-249	250-499	500-999	> 999	Total (%)	*Total (Absolute value)*
Food	0,78%	1,95%	1,17%	0,78%	0,78%	5,45	14
Other Industries	0,78%	0,00%	0,00%	0,00%	0,00%	0,78	2
Paper-Publishing	1,56%	0,00%	1,17%	0,00%	0,00%	2,72	7
Chemical	3,11%	2,72%	0,78%	0,00%	0,39%	7,00	18
Wood	0,00%	0,78%	0,00%	0,00%	0,00%	0,78	2
Machineries	28,02%	15,95%	5,06%	2,72%	3,50%	55,25	142
Non-Metal Minerals (Ceramic)	9,73%	6,61%	1,95%	2,72%	0,78%	21,79	56
Textile	1,56%	1,56%	2,72%	0,00%	0,39%	6,23	16
Total (%)	45,53	29,57	12,84	6,23	5,84	100,00	
Total (absolute value)	117	76	33	16	15		257

Tab.1b: Interviewed firms (2004 survey)

Sector	no. of employees						
	50-99	100-249	250-499	500-999	> 999	Total (%)	*Total (Absolute value)*
Food	0,00%	0,00%	1,43%	1,43%	0,71%	3,57	5
Other Industries	0,71%	0,00%	0,00%	0,00%	0,00%	0,71	1
Paper-Publishing	2,14%	0,00%	2,14%	0,00%	0,00%	4,29	6
Chemical	3,57%	2,86%	0,00%	0,00%	0,71%	7,14	10
Wood	0,00%	0,00%	0,00%	0,00%	0,00%	0,00	0
Machineries	27,14%	17,14%	4,29%	2,86%	5,00%	56,43	79
Non-Metal Minerals (Ceramic)	10,00%	8,57%	2,86%	1,43%	0,71%	23,57	33
Textile	2,14%	1,43%	0,71%	0,00%	0,00%	4,29	6
Total (%)	45,71	30,00	11,43	5,71	7,14	100,00	
Total (absolute value)	64	42	16	8	10		140

Tab. 2a- Environmental innovation, R&D and environmental costs (acronyms defined above)

Indicators	Inno	Inno-em	Inno-wa	Inno-en	Inno-tot	R&D	Inv-env	Env-Costs	Environmental Patents	Auditing voluntary certification Schemes
range	Dichotomous 0/1	Dichotomous 0/1	Dichotomous 0/1	Dichotomous 0/1	between 0-1	% turnover, all firms*	% turnover, all firms*	% turnover, all firms*	Dichotomous 0/1	Dichotomous 0/1
Mean value	0,79	0,49	0,42	0,46	0,41	0,55%	0,78%	0,67%	0,02	0,26

*including all firms, with positive and zero values.

Tab. 2b- Core Variables and time period of reference

Variables	Time period
Environmental innovations, R&D, environmental costs and investments	2001-2003
Techno-organisational innovations, industrial relations, other organisational practices and production dynamics	1998-2001
Firm performances	1995-2000

Tab. 3- Correlation matrix- independent variables

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	NETW-TOT	1,00																								
2	AUDIT	0,21	1,00																							
3	POL-WAS	0,16	0,00	1,00																						
4	POL-EM	0,20	-0,01	0,56	1,00																					
5	R&D	0,03	-0,06	0,03	0,17	1,00																				
6	ENV-INV	0,05	0,09	0,11	0,15	0,36	1,00																			
7	ENV-COST	0,02	0,01	0,09	0,08	0,35	0,37	1,00																		
8	GRANT	0,20	-0,06	0,02	0,15	-0,02	0,16	0,07	1,00																	
9	SIZE	0,06	0,26	-0,04	-0,05	-0,07	-0,01	-0,03	-0,09	1,00																
10	CHEM	0,19	0,03	0,02	0,06	0,08	0,08	0,02	0,19	-0,02	1,00															
11	MACHIN	0,02	0,01	-0,11	-0,07	-0,04	-0,16	-0,22	0,01	-0,04	-0,30	1,00														
12	CERAM	0,00	0,02	0,07	0,03	0,04	0,08	0,21	-0,13	0,00	-0,15	-0,61	1,00													
13	INT-REV	0,02	0,01	-0,07	-0,01	0,00	0,04	0,03	0,22	-0,06	0,17	-0,25	-0,04	1,00												
14	FIN-MKT	-0,01	0,02	0,02	-0,04	0,07	0,09	0,09	-0,21	-0,06	-0,01	-0,08	0,18	-0,29	1,00											
15	GROUP	0,05	0,14	0,05	0,10	0,00	-0,13	0,08	-0,08	0,43	-0,06	0,02	-0,04	-0,02	-0,04	1,00										
16	LIVGER	-0,04	-0,06	0,13	0,09	0,17	0,14	0,14	0,14	-0,11	-0,06	0,06	0,04	0,11	-0,16	-0,12	1,00									
17	%DIP-FORM	0,06	0,20	0,20	0,11	-0,02	-0,18	0,06	-0,01	0,10	0,07	0,00	-0,16	0,07	0,00	0,24	-0,14	1,00								
18	INNO-ORG	-0,06	0,02	0,04	0,08	-0,01	0,01	-0,04	0,11	0,03	-0,04	0,13	-0,17	-0,07	0,08	0,11	-0,20	0,23	1,00							
19	INNO-TEC	0,01	0,16	0,04	-0,04	-0,05	-0,09	0,11	-0,03	0,05	-0,04	-0,05	-0,04	-0,11	0,03	0,11	-0,11	0,11	-0,01	1,00						
20	MAN-vs-EMP	0,04	0,05	-0,14	-0,16	0,11	0,05	0,16	0,00	0,10	0,10	0,04	-0,14	0,15	0,09	0,21	-0,06	0,31	0,23	0,05	1,00					
21	PART	0,01	-0,02	-0,14	-0,01	0,05	0,10	0,00	0,15	0,07	0,01	0,10	-0,12	0,08	-0,15	0,05	0,03	-0,05	0,08	-0,02	0,20	1,00				
22	IND-REL	0,05	0,22	0,07	0,12	-0,08	-0,11	-0,12	-0,09	0,27	-0,19	0,00	0,11	0,01	-0,02	0,23	-0,16	0,01	0,03	0,07	-0,04	0,19	1,00			
23	PROF_95-00	-0,06	0,13	0,09	0,12	0,06	0,18	0,00	0,09	-0,12	0,04	0,20	-0,09	-0,07	0,14	-0,11	-0,03	0,21	0,25	0,05	0,05	0,03	-0,02	1,00		
24	PROD-95-00	-0,13	0,20	0,06	0,08	0,20	0,33	0,12	0,03	0,10	-0,02	0,04	-0,06	-0,03	0,23	0,05	-0,08	0,21	0,22	-0,02	0,16	0,02	0,03	0,65	1,00	
25	INV_N-95-00	-0,04	0,25	0,15	0,17	0,15	0,29	0,08	-0,04	0,37	0,02	-0,30	0,18	0,01	0,12	0,23	-0,12	0,15	0,06	-0,02	0,02	0,03	0,32	0,16	0,54	1,00

The table presents the complete set of potential covariates.

Tab. 4a- Econometric regressions (output innovation)

Dependant variable	INNO-EM	INNO-WA	INNO-EN	INNO-TOT	INNO-TOT	INNO-TOT
Regression	1	2	3	4	5	6
Covariates/Methodology	Probit corrected for heteroskedasticity	Probit corrected for heteroskedasticity	Probit corrected for heteroskedasticity	OLS corrected for heteroskedasticity	OLS corrected for heteroskedasticity	OLS corrected for heteroskedasticity
Constant	-0,945	-1,392	-2,676***	0,941	0,135	0,083
Log-Size	-0,229	-0,754	1,514	0,416	0,196	0,272
CHEM	0,456	0,605	1,846*	1,668*	1,778*	1,579
MACH	-0,149	0,256	1,645*	0,619	0,720	0,547
CERAM	-1,678*	1,822*	2,234**	1,186	1,223	1,318
GROUP		1,971**		1,515	1,758*	1,982**
HYER		-2,078**	-1,125	-1,892*	-1,831*	-1,786*
IND_REL	2,397**		2,546**	2,477**	2,492**	2,293**
POL-WA/EM	2,090**	2,857***				
POL- WA/EM (YRS)	-2,243**	-2,304**				
Grant		1,916*		3,707***	3,194***	3,670***
ENV-INV			(dummy) 2,115**	-0,975		
ENV-COST		1,752*		2,794***	2,397**	
ENV-COST (pred values)	Not significant when included	Not significant when included			Not highly significant when included	
R&D				2,131**		2,535**
R&D dummy	2,081**		Significant at * when included			
AUDIT	2,185**	2,768***		3,076***	2,951***	3,038***
EMAS				EMAS significant at *** when included separately		
ISO_{14000}						
$PROD_{9800}$		1,302				
McFadden pseudo R^2	0,158	0,216	0,154			
Estrella fit	0,213	0,282	0,206			
Adj R^2				0,192	0,200	0,194
Log-L	-81,56	-81,75	-81,75			
Chi-squared LR test (prob chisq>value)	0,0006	0,00004	0,0002			
F test (prob)				3,21 (0,0002)	4,17 (0,0000)	4,05 (0,0000)
Correct prediction: actual 1s and 0s correctly predicted	70%	75%	67%			
N	140	140	140	140	140	140

Notes on regressions

1. fitted values of environmental costs not significant when included
2. fitted values of environmental costs not significant when included; when direct policy proxies are omitted, ENV-COST is significant at **
3. R&D dummy significant at *, regression not shown.
4. EMAS drives the significant of AUDIT
5. fitted values of environmental costs not highly significant when included

Tab.4 presents t ratios (only covariates emerging as significant in final form specifications are shown). We emphasise coefficients which arise significant at 10%, 5% and 1% (*, **, ***).

Tab. 4b- Econometric regressions (Input Innovation)

Dependant variable	R&D	Ln(R&D)	Ln(R&D)
Methodology	Probit	Two-stage procedure	Two-stage procedure
Constant	-4,22***	-2,42**	-2,694**
Log-Size	1,10	-1,37	-1,259
CHEM	2,24**	-0,53	-1,10
MACH	0,99	-1,39	-2,146**
CERAM	2,10**	-0,19	-0,471
FIN-MKT	2,68***		
HYER	2,78***	1,74*	2,188**
IND-REL	2,03**		
MAN-EMP		1,24	
INNO-ORG	1,64		
COV		0,77	2,325**
NET-TOT	1,83*	1,87*	3,972*** (NET-EN)
PROD9800		3,016***	3,418***
GRANT		-2,03**	-1,514
IMR		1,06	0,985
McFadden pseudo R^2	0,157		
Estrella fit	0,209		
Adj R^2		0,192	0,32
Log-L	-80,74	-93,66	-89,34
Chi-squared LR test (prob chisq>value)	30,26 (0,0003)	38,74 (0,0001)	47,37 (0,0000)
F test		2,30 (0,02)	3,91 (0,0006)
Correct prediction: actual 1s and 0s correctly predicted	66%		
N	140	61	61

Tab.4 presents t ratios. We emphasise coefficients which arise significant at 10%, 5% and 1% (*, **, ***).

Tab. 5- Bivariate probit analyses

Dependant variables	*Correlation (T value)*	*Most Significant explanatory factors*
INNO/auditing	0,124 (0,563)	
INNO-EM/auditing	0,410 (2,787)***	Size, performances
INNO-WA/auditing	0,375 (2,513)***	Size, performances, costs
INNO-EN/auditing	0,272 (1,717)*	Sectors, performances
ISO14000/EMAS	0,622 (1,005)	
INNO-EM/INNO-WA	0,459 (3,720)***	Ceramic, investments
INNO-EM/INNO-EN	0,58 (5,271)***	Sectors, investments
INNO-WA/INNO-EN	0,133 (0,947)	
R&D/INV-AMB	0,749 (7,893)***	Networking, ceramic, market revenue, profit, size

N=140; only firm structural characteristics and performances are used as covariates