Examining the Factors Influencing Environmental Innovations

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Summary

Technological innovation is a key factor for achieving a better environmental performance of firms and the economy as a whole, to the extent that it helps to increase the material/energy efficiency of production processes and to reduce 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 Emilia Romagna region -Northern Italy- in 2002 and 2004, located in a district-intense local production system. New evidence is provided by testing a set of hypotheses, 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 input and output-based environmental innovation reduced form specifications in order to test the set of hypotheses. 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, the 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, we provide food for discussion on firm environmental innovation strategies, and research suggestions for further empirical work.

Keywords: Environmental innovation, Environmental R&D, Manufacturing sector, Local system, Environmental policy, Networking

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

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1. Environmental Innovations and environmental policies in industrial settings

1.1 Conceptual framework

The issue of environmental innovation in district-oriented local productive system is particularly important given the high density of firms in industrial areas. This is extremely relevant for some industrialised Italian Regions, since clusters or districts of firms may generate critical harmful local "hot spots" in emission and waste production. 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 and knowledge spillovers due to proximity and internal sources, may dynamically increase the environmental efficiency of the productive area[1]. 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. 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 (Jaffe et al., 2005). Concerning the current European situation, we observe a mounting interest in environmental (less polluting) technologies, partly depending on the contribution they can make to reach the "Lisbon Objectives" on growth and innovation and the "Gothenburg priorities" on sustainable development complementarily (IPTS, 2004)[2].

Specifically concerning manufacturing, pollutant emissions from the manufacturing industries are main determinants for the general pollution affecting the environment, both in Italy and in the European industrial environment. Manufacturing industries, apart from the energy production industry, account for a relevant part of total emissions for respective species. The specific evidence for Emilia Romagna, the region hereby considered, 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.

Regarding innovation adoptions, we may briefly say that 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 are not widespread on average and in industrial districts as well (Iraldo, 2002) for a recent assessment on the EMAS dynamics in Italian districts[3]. The situation is clearly in transition. Industrial districts firms are slowly moving to more advanced approaches based on clean technologies and environmental management schemes.

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[1] Aggeri (1999) calls those informal agreements "innovation-oriented voluntary agreements", where pollution is diffuse, uncertainty is high and innovation becomes the central feature.

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

[3] 148 Italian organisations were registered to EMAS in 2003, of which 87% were northern Italian companies. ISO 14001, the most known and used voluntary eco-label certificate, witnessed an increase of 1000 units in 2002/2003, leading to a total of 2700 certificates, also mostly present in Northern Italy. Recently, even some districts got EMAS certification.

The paper is structured as follows. Next sections briefly sum up recent works and set out the main hypotheses of the study. Section two is split into a first part, where we address data and context, providing some preliminary descriptive examination of data, and a second consequential section which is devoted to the methodological framework and econometric exercises. Empirical evidence is commented. Last section concludes offering insights for future research.

1.2 Empirical evidence: the state of the art

We may subdivide the empirical 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, and contributions focusing on (ii) firm/sector pollution indexes, and (iii) firm performances as dependant variables. 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.

For brevity, we focus only on research line (i)[4]. A seminal work is by Jaffe and Palmer (1997) who study environmental innovation by defining R&D and patents as dependant variables, at industry level. The study aims at empirically investigating the relationship between innovation and policy, rooting on the (ambiguous) set of the so called "Porter" hypothesis (Porter and Van der Linde, 1995). In a panel framework, where two reduced form equations for R&D and patents are modelled, they find that higher lagged abatement costs lead to higher R&D expenditures. They conclude that "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.

Brunnermeier and Cohen (2003) employ panel data on manufacturing industries to provide new evidence on the determinants of environmental innovation. They measure innovation by the number of patents (waste treatment and containment, recycling and reusing, acid rain prevention, waste disposal, alternative energy sources, air pollution, water pollution) and they find, 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.

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), in order to investigate whether environmental auditing schemes (voluntary management-oriented organizational innovation) and pollution abatement innovation are correlated. The main conclusions are that the enhancement of corporate image is a potential force behind the adoption of EMS, while policy inputs do not seem to affect this organizational innovation. In addition, the influence of public authorities and the strictness of environmental policy seem to trigger abatement while EMS and other policy instruments do not.

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[4] Regarding stream (ii), we refer to Cole et al. (2005), Greenstone (2004), Magat and Viscusi (1990), while Gray and Shabdegian (1995), Greenstone (2001), Darnall et al. (2005), Konar and Cohen (2001), Brunnermeier and Levinson (2004) and Gray (1997) are key papers within (iii).

1.3 Examining the factors affecting Environmental innovation: a set of hypothesis

The paper discusses and tests the following hypotheses, mainly assessed by means of econometric analyses[5]:

(1) Policy effect. The role of policies in stimulating innovation is a long debated issue at theoretical and empirical level (Grubb and Ulph, 2002)[6]. A good candidate variable for representing indirect policy action (in absence of direct-policy proxies) are the *induced costs* stemming from policy implementation. Expenses seem to be a reasonable 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) associated to policy implementation and compliance with the policy, by both private agents and by society as large (if social market and non-market costs are also accounted for). Costs can 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. 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)[7].

(2) *Eco-Auditing schemes 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 *AUDIT* for the variable capturing the presence of either EMAS or ISO*,* while EMAS, ISO when included separately). 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[8]. 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, 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

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[5] We specify in brackets acronyms for explanatory factors used in the econometric section.

[6] See Hemmelskamp (1997), Kemp (1997), Mazzanti and Zoboli (2005), Requate (2005) for various conceptual insights and some case studies evidence.

[7] 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).

[8] For an application of the model within the relevant literature see Darnall et al. (2005).

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.

(3) *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 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[9].

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). 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[10]. To our knowledge the link between industrial relations and environmental innovation strategies has very rarely been tested[11].

(4) *Correlation 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[12], positively associated with other innovations. It remains possible that on the other hand, environmental innovations may displace other technological innovations, for various financial and policy related reasons (Jaffe et al., 2005). The most recent literature emphasises that the mere introduction of new technologies, without organisational innovation and new human resource management practices, does not seem to support better performances. Bundles of high-performance practices are needed. The link between techno-organisational innovation and environmental innovation has rarely been tested to our knowledge[13].

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[9] 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.

[10] Our main indicator, ranging between 0 and 1 to represent intensity and quality of management/trade unions/employee relationships concerning firm strategies, is a synthetic index of industrial relations "intensity" concerning high performance practices (IND-REL). It 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.

[11] Frondel et al. (2003) provide some evidence on the effect of unions as a "pressure group", finding ambiguous evidence. See Menezes-Filho and van Reenen (2003) for an overview of empirical works concerning trade unions role in triggering non-environmental innovation.

[12] 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).

[13] Florida et al. (2001) analyse the relationship between organizational resources/organizational innovativeness and EMS schemes, exploiting firm-level data, finding a positive correlation. Organizational factors may thus play a role in the adoption of green designs. In our case, EMS strategies are not correlated neither to any of organizational innovative practices nor to process/product innovations. When including all certification activities (ISO and EMS), correlations ate moderately significant with TQM and process/product innovations.

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 process and product innovation (INNO_TEC) As training is often considered a high-performance practice linked to organisational innovations (Huselid and Becker, 1996), we include among the set of possible covariates for R&D an index of formal training employee coverage (COV). Finally, another proxy of organisational innovation is the flatness of the organisational structure: it has been argued that flatter organizations perform better in terms of innovative dynamics, compared to Fordist-Taylorist more "centralized" firm. Flatter firms should also move easier towards innovation flexibility dynamics rather than defensive strategies (labour cost reduction, labour saving technological process). 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).

(5) *Networking activities are (positively) associated to environmental innovation (through environmental R&D).* R&D is generally recognised as an important innovation measure and an input for innovation output dynamics (technology invention and adoption) and firm productivity in a second stage. This extends to *Environmental R&D*. this is an indicator seldom available in official statistics: we elicited the value as share of turnover, excluding expenses on workplace safety and environmental security.

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 economies of scale in environment characterised by small and medium firms. We elicited data on the source of environmental innovation 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 positive relationship 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 firm investments in co-operative/networking agreements.

The necessary joint effort to establish voluntary co-operative schemes characterises most forms of (i) voluntary agreements, (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. 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[14]. Network relations and high-performance oriented organizational strategies are indeed linked, since they may represent external and internal ways of innovating the organizational firm structure[15]. This kind of formal and informal networking relationships may be interpreted as a quasi-fixed factor of 'production' (Brynolfsson et al., 2002), slow evolving over time, thus exogenous with respect to R&D decisions at least in the short term.

Empirically speaking, we use "networking" dummies (presence of cooperation with other firms and cooperation with research institutes in developing innovations for the four identified innovation areas, from

[14] 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.

[15] See Hansen et al. (2001).

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, synthesizing 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. The networking effect on innovation is included in R&D using a two-stage estimation procedure, where the hypothesis is networking → R&D → innovation.

(6) *Firm structural variables.* Finally, the impact on innovation of *firm structural variables* is assessed by including a vector of control factors. First, 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. We test the hypothesis using the number of employees (including linear and squared terms). The set of covariates also include additional control variables which may act as explanatory factors of innovation[16]. 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 capture a first "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). Concerning firm performances, past productivity is included to test its influence in driving innovation.

2. Empirical analysis of innovation dynamics in an industrial system

2.1 Data and Context

We provide new evidence on the factors associated to environmental innovations, by exploiting a specific dataset rich in information on firm strategies and structure. The dataset is very detailed since it stems from two surveys on the same firms (2002 and 2004, eliciting data respectively on 1998-2001 and 2001-2004 trends). Thus, it only partially suffers from "cross sectional bias", since it is built on two consequential surveys: some of the correlations between innovation and its explanatory factors are not affected by eventual ambiguity regarding the causal direction of the link. It is worth noting that evidence grounding on firm level data possessing detailed richness and representativeness is quite rare relatively to industry-based data since survey based approaches are the only option for data collection (Khanna - Anton, 2002; Lee - Alm, 2004). This also emerges from the above literature review[17].

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[16] 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.

[17] 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 focused industry study.*

Our analysis thus opens some new research directions, widening the vector of potential driving forces of environmental innovation in complex and evolving industrial systems. Although specific to the industrial system here studied, results may allow a generalisation concerning the northern Italian and European industrial situation with respect to the recent trends in environmental innovation.

We ground our applied analysis on a district-based manufacturing local system in Emilia Romagna, specifically the industrial system of Reggio Emilia. 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. The investigation focused mainly on high-performance practices, industrial relations and technological/organisational innovations (Antonioli et al., 2004). 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. 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.

The survey on environmental innovation was carried out by administering a short focused questionnaire to the 199 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 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[18]. We asked then 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 inquired. Further, the adoption of environmental corporate management schemes was elicited. 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 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.

A proof of the good degree of representativeness for the two surveys also 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:

[18] The taxonomy of environmental realms is largely consistent with recent OECD studies (Darnall – Jolley – Ytterhus, 2005) and other recent filed investigations (Gonzalez, 2005). We are aware that we do not analyse the adoption of innovations differentiating by type (end of pipe/structural; process/product). This choice depended on the "constraint" defined by telephone interviews. Future researches using direct on site interviews may collect reliable and more specific data on innovations.

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

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.

2.2 Input/output based Environmental Innovation: preliminary findings

An introductory analysis of data, preliminary to the econometric analysis, is presented on the basis of simple descriptive investigations and basic statistical techniques. First, a full and general framework concerning simple data statistics, with some analysis of variance with respect to size and sectors, is presented. Secondly, an analysis of correlation between environmental innovations is commented following basic bivariate probit analysis outcomes (Darnall et al., 2005). Then, a brief investigation over the eventual complementarities among some hypothesised output innovation inputs is provided, opening space for future research on that direction.

2.2.1 Descriptive statistics

A 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%[19]. Finally, firms adopting all four forms of innovations are less than 10% of the sample. This is consistent with the non homogenous relevance of all four realms of innovation by sectors.

Innovation intended as the adoption of (voluntary) auditing schemes (EMAS, ISO[20]) concerns 26% of firms[21]. We can partially compare this outcome with that of Frondel et al. (2004) 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). EMAS is only present in the firms of the ceramic sector, which has experienced the achievement of a district-based EMS certification. The lower number of firms involved in EMS is compatible with the more stringent rules and the European level of EMAS scheme. Only 3 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) [22].

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[19] 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%.

[20] 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).

[21] Regarding a US study, Florida et al (2001) estimate that 24% of manufacturing firms with more that 50 employees adopt EMS schemes.

[22] Defined as "A collection of internal efforts at formally articulating environmental goals, making choices that integrate the environment into production decisions, identifying opportunities for pollution reduction and implementing plans to

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 defence 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 output 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. 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 and cooperation are concerned, it is worth noting the paper by Karl et al. (2005), presenting a case study based analysis of forms of cooperation regarding innovation in general and environmental innovations, using data for Germany concerning 1999 and 1995. They show cooperation intensity indexes (percentage of firms involved at last in one exchange) for all industrial sectors: machinery and chemical are associated to the highest score. Our data confirms that the chemical sector is the most intense in cooperation regarding environmental issues (the only one with a significant correlation). Disaggregating by environmental objectives, results do not change: the chemical sector overwhelms the other two main sectors (machinery and ceramic) in terms of correlations with networking activities, with other firms and research institutes. The correlation is highest for energy-related objectives. They also show that the link between firm size and cooperation is positive, but weaker when focussing only on environmental objectives; looking at correlation indexes, our data show that the relationship is significant and positive for waste-related objectives and when considering a total networking index. Such correlations never overcome a 0,15 threshold; size and networking tend to be quite independent to each other as explanatory factors. Table 2c shows a moderate but not monotonous size effects.

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make continuous improvements in production methods and environmental performances. They establish new organizational structures to gather information and track progress towards meeting environmental targets" (Khanna and Anton, 2002, p.541).

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[23]) the mean value is instead barely 0,6% and 0,8% of turnover (with maximum values of 10%) or 2000€ per employee. 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.

2.2.2 Size and sector effects

We now descriptively examine the extent to which innovation is influenced by size and sector (tab 2c). 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. The effect is dependant on the environmental realm. 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.

By sector, we first note that textile shows the lowest involvement in environmental issues within manufacturing, as expected (it is historically a low innovation sector). Concerning the most relevant sectors, 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 are intense in the ceramic sector (57%). Ceramics has also the highest score (60%) for energy efficiency innovations. All in all, chemical and ceramic sectors confirm to be highly involved in local environmental issues in the Region, and responding with higher innovative efforts.

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 clear size effect. Table 2c shows that both in terms of investments and in terms of firm shares, size cannot be identified as a crucial factor. For capital investments, an inverted U shape arises, with largest firms showing the lowest value. Medium-large sized firms show the highest values. As far as costs are concerned, no size effect emerges, 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 0,0%), paper-publishing and textile for capital investments and also for environmental costs (respectively 2,6%/0,0% and 1,7%/0,0%).

To summarize dimensional and sector effects, tab. 2c presents the mean values of output innovations, R&S, Investments and environmental costs for each defined dimensional class and for main sectors. A general

[23] 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.

conclusion stemming from the descriptive analysis is that sector effects on innovation, as expected, prevail over size effects, on both input and output sides of the innovative process. Environmentally critical sectors like chemical, ceramic and also paper seem to be more involved in innovative dynamics. Medium and medium-large firms emerge overall as the more involved, but the picture is quite heterogeneous by type of innovation and index considered. Although size effects on innovation only weakly emerge from the case study, we should point out that a stringer structural break could have been observed if firms under 50 employees had been included. Firms under that threshold represent the 50% of the productive structure of the area. Size and sector effects will be further investigated in the multivariate analysis that follows, in order to find more robust evidence.

2.2.3 Environmental innovations correlations and input complementarities

As a second point of analysis in this section, on the output side, a bivariate probit analysis is carried out to test the correlation between various environmental innovations (tab 2d). The adoption of emission reduction technology is correlated to waste and energy oriented technologies. Waste processes are also correlated with material input reduction strategies. Overall, the set of correlations, as emerging from a series of bi-variate probit studies, confirm that the innovative dynamics, both on the technological and on the techno-organizational side, are generally (with some exception) highly correlated to each other, perhaps because environmental innovations is pursued by a limited number of innovative firms which are more committed on all environmental grounds. This result opens the way to further investigation aimed at assessing what the drivers of innovation in its different specifications are.

As a final analysis of this section, we focus on complementarities among innovative outputs and innovation drivers (tab 2e). As far as the latter is concerned, we briefly check complementarities exploiting a discrete data formulation for innovation drivers (Mohnen and Roller, 2005): we focus on auditing, R&D and induced costs. Some notes on complementarities are possibly drawn out from the observation of count statistics (tab.2e). For example, taking R&D and auditing (using tab.2e as reference), the occurrence of input combinations (000) and (110) is more frequent than (010) and (100): 32% vs 11%. But (001) and (111) are less frequent than (101) and (011): evidence is thus mixed. Concerning R&D and Costs, we note that (000) and (011) are much more frequent than (010) and (001); (100) and (111) are also more frequent than (101) and (110): complementarity holds. Finally, auditing and induced costs do not show complementarity in both comparisons.

It is obvious that count statistics suggest only a preliminary evidence on complementarities among innovation inputs. A full examination by systematic multi-variate analysis is beyond the scope of the present paper. It is food for further research.

2.3 Methodological issues in modelling innovation

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 "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. In fact, one aim of the paper is 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, towards a richer and more extended "innovation production function". Econometrically speaking, we attempt define the largest set of *independent* (non correlated) factors in order to minimise omission of possible relevant variables.

We claim that when studying innovation from an applied perspective, a feasible and plausible way (see also the literature review in par.1.2) is to define reduced forms which attempt to explain innovation by exploiting a theoretically consistent set of covariates (Mohnen and Roller, 2005; Cassiman and Veugelers, 2002). This is a usual practice within the technological and organisational innovation oriented literature, which broadly exploits the frame of a "knowledge production function" (Griliches, 1979) and then in the specific sub-realm of environmental innovation[24] (Brunnermeier and Cohen, 2003; Jaffe and Palmer, 1997; Khanna and Anton, 2002; Lee and Alm, 2004). Attention is to be devoted both to the reliability/availability/quality of data and to the correct matching between the nature of the dependant variable and the statistical model used for the analysis.

On the other hand, innovation models aim at highlighting what exogenous and endogenous forces, external and internal to the firm, impact on techno-organizational dynamics. Historically, the literature has extended the hypothesis on potential innovation drivers by adding policy proxies and other less standard firm strategies to the usual R&D and firm structural characteristics. External and internal factors should both be extensively tested as possible drivers of innovation; this has been enlarging the applied research perspective during recent years (Florida et al. 2001).

As said, this extension of potential covariates is important even from a methodological perspective. In fact, different biases arise when 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). Thus, a procedure aimed at extending, given data availability, the set of innovation drivers, is methodologically sound and does not lead to structural model distortions.

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, omitted variable issues and other potential flaws affecting the analysis.

To set out the largest set of *independent* (non correlated) factors, a preliminary analysis must be carried out for studying the full correlation matrix, concerning all potential covariates, dropping high-correlated potential

[24] Hansen et al. (2001) present an analysis of case studies regarding environmental innovations in small and medium sized enterprises, for five European countries. The study reveals a great variety in factors driving the process: character of environmental innovation, regulatory setting, firm strategic orientation, network relations, sectoral influence. Innovative capability emerges as the result of the interplay between different driving forces. Very recent evidence, concerning pulp and paper industries, on the variety of factors affecting environmental innovations, is provided by Gonzalez (2005) and Doonan et al. (2005).

regressors. This first selection is aimed at reducing collinearity problems, selecting a limited set of covariates for testing each specific hypothesis. The outcome is a matrix of *selected* potential explanatory variables (correlation values for selected regressors are shown in tab.3[25]). Besides few variables indexes, which will be consequentially cautiously introduced, the final correlation matrix shows low figures concerning main independent variables. Concerning regression analysis, a "from general to particular" backward stepwise method is applied. 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 investments relating to environmental innovation.

(a) Innovation output

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[26] of a production function:

$$(1) \quad INN_{i,t} = \beta_0 + \beta_{1,t}(\textit{structural firm features}^{27}) + \beta_{2,t/t-1}(\textit{environmental policy}) + \beta_{3,t}(\textit{environmental R\&D}) + \beta_{4,t}(\textit{environmental direct costs}) + \beta_{5,t-1}(\textit{techno-organisational innovation}) + \beta_{6,t-1}(\textit{industrial relations}) + e_i$$

where INN_i represents the environmental innovation output of firm i, and e_i the error term with usual properties. β_0 is the constant term, β_{1-8} the set of coefficients associated to explanatory variables, where (t) stays for 2003-2001 and (t-1) for 2001-1998.

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. Panel dataset *may be* a better framework for coping with it. Nevertheless, the nature of techno-organisational innovation, intangible assets, networking and policy-related data, all potential drivers of innovations, often prevents 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 (thus specifying an hybrid cross sectional model) for all relevant covariates (for an example see Khanna and Anton, 2002). Exploiting the two survey waves, most of our drivers are temporally preceding innovations (2001-2003). For R&D, we use both the elicited 2001-2003 value and the predicted values stemming from a first stage R&D regression, in order to cope with endogeneity between R&D and innovation. Though the direction of causality is

[25] 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.
[26] Even without assuming the usual neo-classical properties concerning production inputs.
[27] Size, market features (national market share, subcontracting share), sector, district membership, etc...

not ambiguous in this case (from R&D to innovation)[28], the use of a two stage procedure may help making estimates more robust (see par.3.2).

When estimating a 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 that there is not an "optimal" econometric model for studying fractional variables. Although OLS estimates in this case 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 are not a panacea. It is possible to verify that estimates deriving from OLS, OLS based on (log) transformations (when this is possible given the observed "0s") and Tobits do not differ significantly as far as coefficient signs and "relative" statistical significances are concerned (Pindyck and Rubinfeld, 1991), although coefficient "levels" are different across models. 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.

Other statistical models could be exploited for testing the validity of results and specifications. We here do not deal with patent-like data (Brunnermeier and Cohen, 2003), which obviously require a (Poisson-based) model for count data. We argue that a (synthetic) index on different innovation adoptions ranging from 0 to 1 is a preferable alternative to count-like specifications of the dependant variable *when* we observe a number of innovation typologies over a range (necessarily) defined by the researcher (we are not counting an intrinsic discrete real phenomenon, like patents or specific innovations per se). In addition, as said above, using innovation intensity indexes, the aim is not estimating elasticities but finding a ranging over explanatory factors. Thus, the variable "number" of innovation typologies does not properly and necessarily fit within a count model (conceptually, we are not effectively facing a discrete count variables) and even less with ordered probit frames (Khanna and Anton, 2002)[29]. Nevertheless, a final "external validity" test using count models (specifying as dependant variable the number of typologies of innovations adopted) is carried out, in order to compare outcomes (Woolridge, 2002, ch.19). The methodological issue is in any case open to and worth of further investigations.

(b) *R&D Innovation input*

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

[28] When data are purely cross sectional and two-way causal relationships between variables are a critical issues, applied analyses may only aim at highlighting "correlations" rather than causal processes (Michie and Sheehan, 2005).

[29] The point is critical in methodological terms and quite unresolved. In our opinion, ordered models are appropriate when we face ratings, voting and other ordinal observed phenomenon. Count models fit data which effectively represent a discrete counting of a variable going from 0 to infinite. Concerning innovation adoptions, the number of innovations is defined by the researcher: setting up an index is one of the ways to capture a sort of "innovation intensity", leading to fractional variable frameworks.

wrongly labeled censored regressions, though the issue is not data observability as in censoring and truncation. 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 used and compared. Finally and alternatively, a probit model specifying as "1" firms with positive R&D is also tested.

2.4 Econometric results

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

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: (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[30].

2.4.1 Input innovations

We begin commenting the outcomes for the R&D *input innovation* equations.

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 outcomes. Ceramic and chemical are the only sectors 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

[30] 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.

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 (see below opposite results on innovation output indexes)[31].

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 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) are: the networking effect increases its significance level, although within a 10% statistical threshold. Among structural features, only the chemical industry seems to positively influence R&D. R&D is also positively correlated to past productivity[32].

As a final analysis, we use a two stage procedure, finding no evidence of a two-tier process (last column tab.4b). The model fit is nevertheless good. Networking, organisational factors (flatness), industrial relations 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 networking effects, this preliminary evidence highlights the role of cooperation with other firms and research institutes. The regression including energy-related networking dummy is associated to higher fit measures.

[31] 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.

[32] 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).

2.4.2 Output innovations

As far as *output innovation* proxies are concerned, the following outcomes derive from binary Probit analysis[33] capturing all four realms of innovation (INNO-TOT). OLS robustly corrected estimates show (tab.4b) that (i) R&D and induced costs are significant while investments are not[34]; (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. Auditing schemes are significant (with EMAS dominating over ISO14000 when separately included). 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.

Alternatively, count data models do not provide a striking different evidence (regressions are not shown but are available upon request). Signs do not change while statistical significance is slightly changing with respect to OLS: flatness decreases its impact, the chemical sector increases its role. R&D and costs are significant both when separately included; and when included together. Though there is no natural counterpart to R^2, goodness of fit may be measured by various fit measures, some bounded between and 1 and reported in tables. A critical issue is the assumption that the variance of y equals the mean in the Poisson model. In effect, the test on dispersion would suggest the use of a negative binomial model, which nevertheless may present convergence estimation problems when facing numerically limited samples. In our case, the number of iterations in the negbin model sharply changes with the inclusion/omission of some variables. Using the same covariates of the Poisson model above, some coefficients lose significance. Our data also present a 28% of zero observations and an upper bound at four innovations. Thus, censoring and especially truncation specifications may be tested even in the count data framework. As expected, fit measures and overall significance favours the truncated model, which presents better fit measures compared to the standard count specification. The vector of significant covariates nevertheless shrinks to industrial relations, auditing schemes (jointly taken), and chemical sector. R&D does not emerge significant, while costs do when predicted values are introduced.

2.4.3 Main outcomes

The main outcomes to be summed up are the following. 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.

[33] The index takes values 0; 0,25; 0,50; 0,75; 1. As discussed, it may be analysed using different econometric specifications. Probit regression on specific output innovations (analyses on innovation adoption) are not shown here. All estimates and data are available upon request. Results do not change; overall, the statistical significance of auditing, R&D and induced costs emerge over structural firm features.

[34] 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.

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 positive and high, this 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.

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 favour 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 spillovers 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[35]. 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). In our case, EMS and ISO seem to possess an innovative content, perhaps because such schemes, whose effectiveness is often disputed, are not widespread and exploited by a limited number of more innovative firms.

[35] 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.

3. Concluding remarks

The paper provides new empirical evidence on the forces affecting environmental innovation at a firm level. We exploit a recent and rich survey based datasets covering market and non market firm features. The focus is on local production system and 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.

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.

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. Further research is also needed towards the understanding of the interaction effect on innovation of environmental and technology policies.

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 (iii) environmental (policy related) costs, (iv) R&D and, final but not less important, (v) 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. While not the only driver, policy actions emerge very relevant, with a possible multi-faceted scope of intervention: to stimulate and monitor auditing schemes, to provide incentives for environmental R&D and (associated) cooperative networks, and to increase the costs of managing environmental resources to induce innovation adoptions. 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 innovations, R&D and environmental costs: descriptive statistics

Main Indicator variables	Type	Mean value	Maximum value	Minimum value
Adoption of any environmental innovation	Dichotomous 0/1	0,79	1	0
Adoption of emission reduction related innovations	Dichotomous 0/1	0,49	1	0
Adoption of waste management related innovations	Dichotomous 0/1	0,42	1	0
Adoption of energy reduction related innovations	Dichotomous 0/1	0,46	1	0
Adoption of material input reduction related innovations	Dichotomous 0/1	0,27	1	0
Synthetic index of the adoption of environmental innovations	between 0-1	0,41	1	0
Environmental R&D	% turnover, all firms*	0,55%	10%	0%
Environmental Investments	% turnover, all firms*	0,78%	10%	0%
Environmental costs	% turnover, all firms*	0,67%	16%	0%
Environmental Patents	Dichotomous 0/1	0,02	1	0
Auditing voluntary certification Schemes (EMS or ISO)	Dichotomous 0/1	0,26	1	0

*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. 2c- Dimensional and sector effects: descriptive summary (mean values)

	Innovation (at least one form)	Emissions reduction innovation	Waste related innovation	Energy related innovations	Material reduction innovations	Four innovations Composite index (0-1)	R&D*	R&D>0	Investments*	Investments>0	Costs*	Networking index (0-1)§
<100 employees	71,88%	39,06%	34,38%	37,50%	25,00%	0,340	0,71%	37,50%	0,70%	42,19%	0,47%	0,152
100-249	80,95%	47,62%	50,00%	42,86%	21,43%	0,405	0,32%	45,24%	0,75%	61,90%	0,90%	0,208
250-499	93,75%	75,00%	50,00%	68,75%	31,25%	0,563	0,42%	56,25%	0,85%	68,75%	0,42%	0,172
500-999	87,50%	62,50%	37,50%	87,50%	50,00%	0,594	0,73%	37,50%	2,15%	62,50%	0,19%	0,281
> 999	80,00%	60,00%	50,00%	50,00%	50,00%	0,525	0,56%	60,00%	0,23%	30,00%	1,81%	0,225
Chemical	80,00%	60,00%	50,00%	50,00%	50,00%	0,525	1,30%	60,00%	1,36%	40,00%	0,58%	0,350
Machinery	79,75%	49,37%	35,44%	44,30%	29,11%	0,396	0,48%	40,51%	0,44%	49,37%	0,47%	0,184
Ceramic	81,82%	42,42%	57,58%	60,61%	21,21%	0,455	0,64%	60,61%	1,29%	66,67%	1,20%	0,182

* % firm turnover, all firms included; the first five columns report the share of firms adopting such innovations. § networking index takes value one when firms cooperate for developing innovation for all four environmental realms considered; then takes values 0,75; 0,50; 0,25; 0.

Tab. 2d- Bivariate probit analyses (correlation values)

Dependant variables	*Correlation (T value)*
INNO-EM/INNO-WA	0,459 (3,720)***
INNO-EM/INNO-EN	0,58 (5,271)***
INNO-EM/INNO-MA	0,08 (0,574)
INNO-WA/INNO-EN	0,133 (0,947)
INNO-WA/INNO-MA	0,399 (2,898)***
INNO-EN/INNO-MA	0,274 (1,870)*

N=140; only firm structural characteristics and performances are used as covariates.
Regression estimates are available upon request.

Tab. 2e- Occurrence of innovation inputs states (Auditing, R&D, induced costs)

000	111	001	011	100	110	010	101
No input	All inputs	Induced costs	R&D and induced costs	Auditing schemes	Auditing schemes and R&D	R&D	Auditing schemes and induced costs
29%	11%	15%	26%	7%	3%	4%	5%
State ranking							
1	4	3	2	5	8	7	6

Notes: states are mutually exclusive; they sum up to 100%. The value 0 represents the state/input is not present at firm level, the value 1 that the state/input is present (i.e. "000" for firms which do not present any of the three states, "010" for firms which report only a positive R&D value, "110" for firms with auditing schemes and positive R&D, etc..).

Tab. 3- Correlation matrix- independent variables

	acronym	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
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	COV	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	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	1,00		
21	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	-0,02	1,00	
22	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	0,03	0,65	1,00

The table presents the complete set of potential covariates.

Tab. 4a Summary of main hypotheses

Hypothesised influencing factors	Incidence on Output innovations	Incidence on R&D
Firm structural variables	(+, -)	(+, -)
(past) Firm performances	(+)	(+)
Policy actions / Policy induced costs	(+)	(+)
R&D	(+)	
Industrial relations	(+, -)	(+, -)
organisational/technological innovation	(+, -)	+
Networking activities		(+)

Tab. 4b- Econometric regressions (output innovation)

Dependant variable	INNO-TOT	INNO-TOT	INNO-TOT
Regression	1	2	3
Covariates/Methodology	OLS corrected for heteroskedasticity	OLS corrected for heteroskedasticity	OLS corrected for heteroskedasticity
Constant	0,941	0,135	0,083
Log-Size	0,416	0,196	0,272
CHEM	1,668*	1,778*	1,579
MACH	0,619	0,720	0,547
CERAM	1,186	1,223	1,318
GROUP	1,515	1,758*	1,982**
HYER	-1,892*	-1,831*	-1,786*
IND_REL	2,477**	2,492**	2,293**
POL-WA/EM			
POL- WA/EM (YRS)			
Grant	3,707***	3,194***	3,670***
ENV-INV	-0,975		
ENV-COST	2,794***	2,397**	
ENV-COST (pred values)		Not highly significant when included	
R&D	2,131**		2,535**
R&D dummy			
AUDIT	3,076***	2,951***	3,038***
EMAS	EMAS significant at *** when included separately		
ISO_{14000}			
McFadden pseudo R^2			
Estrella fit			
Adj R^2	0,192	0,200	0,194
Log-L			
Chi-squared LR test (prob chisq>value)			
F test (prob)	3,21 (0,0002)	4,17 (0,0000)	4,05 (0,0000)
Correct prediction: actual 1s and 0s correctly predicted			
N	140	140	140

Notes on regressions

1. EMAS drives the significance of AUDIT
2. 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. 4c- 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% (*, **, ***).

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