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Abstract

Innovation is a key factor in firms achieving a better environmental performance, to the extent that it helps increasing the material/energy efficiency of production processes and reducing emission/effluents associated with outputs. The scope of the paper is twofold. First, new evidence is provided by testing a set of hypotheses, with regard to the influence of a wide array of innovation drivers. Secondly, we analyse the hypothesis of a complementarily relationship with regard to both different environmental innovation outputs and innovation drivers, such as R&D, policy related costs, auditing schemes and networking firm activity.

The applied investigation shows that usual structural characteristics of the firm and performances appear to matter less than eco auditing, R&D, policy related costs, and also organisational flatness and innovative oriented industrial relations. As far as innovation outputs are concerned, the correlation analysis shows that firms which do innovate tend to pursue different environmental innovations jointly. Positive correlations emerge in consistency with expectations. At the level of innovation drivers, we observe that the complementarity link, though predominant across the various analysed couples of drivers, is associated with more heterogeneous evidence, sensitive to the typology of innovation and investigated drivers. As far as the analysis of complementarity is concerned, our results show that the hypothesis of complementarity generally holds.

Although our analysis overall supports the hypothesis of correlation/complementarity between drivers, we even find cases where such main drivers, policy related costs, R&D, networking and auditing, are not complementary. This kind of analysis is extremely relevant for feeding policy making at the level of firms or districts.

Thus, though relevant for explaining innovation dynamics, and crucial for informing management and policy efforts complementarity is then not the all inclusive panacea for tackling the complexity of the environmental innovation system, both from the management and the policy action sides.

Jel: L60, O13, O30, Q20, Q58

Keywords: Environmental innovation, complementarities, auditing, R&D, policy related costs, networking, manufacturing sector

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1. Introduction

The issue of environmental innovation in local productive system is particularly important given the high density of firms in industrial areas. This is extremely relevant for some industrialised regions, since clusters or districts of firms may generate critical harmful local "hot spots" in emission and waste production. 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]. 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 spillovers and on the other hand reducing environmental externalities (Jaffe et al., 2005). With regard to the current European situation, we observe a mounting interest in environmental (less polluting) technologies, partly depending on the contribution they can make to jointly reach the "Lisbon Objectives" on growth and innovation and the "Gothenburg priorities" on sustainable development (IPTS, 2004)[2].

The scope of the paper is manifold. First, new evidence is provided by testing the influence, on the adoption of diverse typologies of environmental output innovations, of: (i) firm structural variables; (ii) environmental R&D; (iii) environmental policy related costs; (iv) other non-environmental techno-organizational innovations and (v) quality/nature of industrial relations. On such premises, complementarity analyses regarding adopted innovations and innovation drivers are carried out. Then, as a second step, a series of complementarity tests between different environmental output innovation choices is carried out. As environmental output innovation proxies, we use both three binary indexes for the adoption of innovations with regard to waste, energy and emissions, and a synthetic index of innovation intensity. Thirdly, we analyse the hypothesis of a complementarity relationship with regard to innovation drivers using a discrete based framework. The primary aim is to test the complementarity between the voluntary auditing schemes with the policy-driven costs and the firm strategy on R&D. We are interested in assessing whether such EMS/ISO (broadly defined as managerial and voluntary approaches to tackling environmental targets) are complementary to innovative strategies (R&D); and to a policy-driven top down effect. This is crucial for informing environmental policies which operate on all sides: incentive R&D given potential market failures, supporting auditing for promoting environmental corporate effort and mitigating free riding behaviour in regional contexts, imposing additional costs through a diverse set of policies, typically taxes on emissions, energy use, and waste disposal.

[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".

Further, we also test the complementarity between internal strategies (R&D) and externally driven factors (policy related costs / networking devoted to innovation) in stimulating innovations.

Summing up the core message of the paper, we first assess the main drivers of output innovations, then we test their complementarity in a bivariate probit setting, and finally we focus on the complementarity which characterise input drivers of output innovation: R&D, policy-driven costs and auditing.

The paper is organized as follows. The next section introduces the analysis of environmental innovation jointly with the issue of complementarity among productive factors. In section three, the database and the context are presented. Section four comments on the main theoretical hypotheses and discusses some methodological issues, introducing the core empirical part, subdivided into an initial analysis of innovation drivers and then specific investigations of complementarity relationships among innovation outputs and inputs. The last section concludes the paper by summarising results and offering insights for further research.

2. Firm performances, innovation and complementarities.

2.1 Environmental innovations and firm strategies

With regard to the evidence on environmental innovation, 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 to empirically investigate the relationship between innovation and policy, basing itself on the "Porter" hypothesis framework (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 expenditure. 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 expenditure, while monitoring and enforcement activities associated with 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.

On the link between environmental innovation and auditing schemes like EMS and ISO we note instead 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. More specifically in the realm of SMEs, that represent 80% of EU firms and are the backbone of most industrial systems, McKeiver and Gadanne (2005) present an extensive taxonomy and empirical analysis of what benefits may drive EMS implementation in SME firms.

They analyse in a connect of SME (firms with less than 200 employees) the external and internal factors that may affect the adoption of formal and informal audit schemes like EMS and ISO14000. Formal schemes are defined as proper adoption of EMS/ISO, while informal activities are more related to environmental innovation and management occurring within an organization (waste management, energy conservation). Informal auditing thus conceptually links the realm of eco-auditing with the realm of environmental management and technology in a broader meaning. This reasoning confirms that both informal and formal schemes may present some complementarity link with environmental innovation adoption and environmental R&D. Biondi et al. (2000) propose an evaluation of efficiency and effectiveness of EMS/ISO management tools focused on SMEs. Such schemes may on the one hand complementarity connect to proper technological innovations, improving overall and /or environmental efficiency of the firm, while on the other hand increase the market value added of firms, through increasing the market niche and the mark up on average costs consumers are willing to pay. Main barriers to auditing implementation are direct financial costs and indirect costs largely associated with human capital investments and management (opportunity) costs.

The surveyed papers provide the most recent evidence on the links between auditing, as part of a wider environmental organisational innovatory strategy, and environmental technological innovations[3]. Specific focus on complementarity with regard to drivers of innovation and performances is not present, nevertheless, in such a literature. One aim of this paper is bringing together the literature on environmental innovation and the framework of innovation, performances and complementarity at a general level of reasoning[4].

[3] We deal with contributions which analyse the factors associated with environmental innovations defined as dependant variable in a conceptual model. Other works dealing with impact of regulation on environmental indicators and the effects of environmental factors on firm performances are Cole et al. (2005), Greenstone (2004), Gray and Shabdegian (1995), Konar and Cohen (2001).

[4] Analyses on the extent to which eco-innovations and "normal" innovations differ see the seminal conceptual paper by Rennings (2000).

2.2 Innovation, performances and complementarity

We here turn our attention to the general issue of innovation and performances relationships, narrowing down the focus to the role of complementarity (related to innovation/performance drivers) in such an analysis. The issue has been addressed both from a theoretical and empirical perspective over the past ten years. A critical survey of the extensive and increasing literature is not the aim of the paper[5].

The relevancy of complementarity among drivers of performances has been underlined by works within the wide range of literature dealing with the relationship between innovation strategies and performances at firm level. Since the mid nineties, those contributions have highlighted the limited short run effects of strategies biased towards organisational (cost) efficiency and the higher potential for increasing long run performance of innovation based management of firms (Huselid, 1995; Black and Lynch, 1996, 2001, 2004; Ichniowski et al., 1997, 2005; Michie and Sheehan, 2003, 2005; Bryson et al., 2005; Matteucci et al., 2005; Cassidy et al., 2005). The questions relevant to this approach and to the more circumscribed environment of complementarity are "by what mechanisms a high performance work system affects firm performance and "how can these systems represent *a source of sustained value creation, rather than simply locus of cost control*?" (Becker, Huselid, 1998).

We refer to Laursen and Foss (2003), Lokshin, Carree, Belderbos (2004), Galia, Legros (2004a,b), Bresnahan, Brynjolfsson, Hitt (2002); Brynjolfsson, Hitt, Yang (2002); Brynjolfsson, Hitt (1997, 2000, 2003), Laursen, Mahnke (2001), Aral, Weill (2005), Guidetti, Mancinelli, Mazzanti (2006) as main recent contributions dealing with complementarity among productive inputs or more generally firm modules. Complementarity is analysed with regard to diverse factor affecting firm performance such as technological innovation, R&D, organisational innovations, high performance practices, training, networking[6] (Becker and Huselid, 1998). Various hypotheses of complementarity are explored, both with respect to their effects on firm performance (productivity, profits) and regarding innovation performances (Pini, 2006). Complementarity is also studied, along a different conceptual and empirical perspective, by more evolutionary, systemic oriented and dynamic focused streams of research. For example, complementarity in Teece (1996) emerges associated with the joint asset specificity of some inputs and innovations, which may produce idiosyncratic non-replicable organisational frameworks, leading to higher performance and rents.

[5] Tab. 6 sums up the main recent empirical contributions on complementarity.

[6] Recent works on networking are by Fritsch and Franke (2004) and Belderbos et al (2004). The first work estimates a knowledge production function in order to verify the impact of R&D investments, cooperative R&D and knowledge spillovers on the adoption of patents and the number of registered patents. The second analyses the effect of various cooperative activities (with subcontractor, with other competitors, university, etc..)on innovation and productivity, finding a weak evidence for the networking-productivity link and an heterogeneous evidence, depending on the cooperative activity, for the link between networking R&D and output innovation

Other works which address the issue within this aforementioned framework, mainly using case study analysis or modelling simulation approaches, are among others, Langlois (2000), Kaufmann et al. (2000), Marengo and Dosi (2005).

It is worth noting at this stage that the aim is different from works which concentrate on the knowledge spillovers of firms' innovation activity. The concept of complementarity is different from that of positive spillovers. Differently from spillovers, hence, if a relationship of complementarity is found between two activities of a firm, this implies that if one of the two activities is increased, it will be more attractive for the firm to increase the other activity too, and system effects arise, with the whole being more than the sum of the parts. This has obvious implications on both firms' strategies and policy decisions. Actually, when two or more activities of a firm show complementary relations, firm and policy efforts should be targeted toward all the activities, since it is possible that improving only one of them would even worsen the firm's performance[7].

The empirical analysis of input complementarity in environmental economics empirical literature dealing with innovation at micro level is new. It brings together the streams of research on environmental innovation at firm level and the research lines on complementarity.

2.3 Testing complementarity

2.3.1. Methods

On the basis of such literature, we may affirm that three methodologies exist in the literature for assessing the complementarity hypothesis. The first analyses complementarity by studying the correlation of two or more variables, controlling for other factors. A usual way of carrying out such a test is by setting a bivariate or multivariate probit model, where complementarity arises if the null hypothesis of no correlation between the residuals of the two or more probit regression is rejected. In this case the variables under scrutiny are the dependent elements of the empirical model (Galia, Legros, 2004b; Laursen, Mahnke, 2001).

The second approach is defined as reduced form approach (Arora, 1996): the analysis of complementarity is carried out by focusing on the effects of two factors, and on their correlation. It is typically implemented by setting interaction terms. The limit is the focus on only two elements (Athey and Stern, 1998).

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[7] On this subject, it is worth quoting the example described in Milgrom and Roberts (1995, p. 194): "General Motors, once the most successful of mass producers, spent some $80 billion during the 1980s on robotics and other capital equipment normally associated with the new methods. It did not, however, make any serious adjustments in its human resources policies, its decision systems, its product development processes, on even in its basic manufacturing procedures. Either it failed to see the importance of making these complementary changes or else, it was unable to make the changes that were required on these dimensions. The result was that those billion dollars were largely wasted.".

The third approach is the one which allows greater flexibility and it is currently the most widespread. We may define it the "productivity approach": it can deal with two or more factors on which the hypothesis is tested, and it is based on the estimation of an objective function, either a production function or an innovation function. Within it, two ways are potentially highlighted. The most common one is assessing the hypothesis by testing the significance of interaction variables, which capture the complementarity effect (Laursen and Foss, 2003; Brynjolfsson, Hitt, Yang, 2002 among the others). A more recent and highly flexible way is to analyse complementarity within a discrete framework where given two or more factors, the hypothesis is tested by evaluating the effects of all possible states of the world, associated with complementarity or substitutability.

Summing up, the present paper focuses on the complementarities of innovation drivers in a discrete setting, taking the first and third approach listed above as main reference. Since we deal with a framework, described below, of innovation functions, the first method is used to verify correlations between different innovation adoptions (e.g. in emission and waste). Within the aforementioned third approach we instead focus on innovation drivers, implementing the test not by the most usual analysis of interaction terms signs and significance, but by referring to the theoretical and empirical framework of Milgrom and Roberts (1990, 1995), Topkis (1978), Amir (2005)[8]. In discrete settings, quoting Mohnen and Roller (2005, p.1432): "the formalization of complementarities to discrete structures permits the analysis of such complex and discrete entities as organizational structures, institutions, and government policies. It provides a way to capture the intuitive idea of synergies and systems effects".

2.3.2 Testing in a bivariate discrete setting

As said, we here present evidence exploiting both the first correlation based approach and the productivity approach, in a discrete setting. The correlation approach is exploited in order to test the correlation, within a bivariate probit, between different environmental innovation outputs. The second approach analyses complementarity relationships with regard to innovation drivers. The selected drivers are R&D, policy related costs, auditing schemes and networking activity

Some more words on the discrete framework are necessary. In order to pursue the analysis of complementarity in a discrete world, we consider an objective function, in our case an innovation function. We thus estimate the function in order to recover the full set of parameters for the driver's states of the world, then testing the null hypothesis of complementarity among innovation drivers. We note, and refer to Mohnen and Roller (2005), and, above all, Milgrom and Roberts (1990), that whenever actions are complementary the innovation function is super modular in its

[8] Empirically, complementarity is often tested by adding interaction terms. This may pose problems of collinearity. Moreover, with more than two variables taken together, this approach implies a substantial loss of degree of freedom.

components. We add that in the discrete setting, it is sufficient to test pairwise complementarity. Then, the function is super modular over a (chosen) subset of its arguments, if and only if all pairwise elements satisfy the complementarity definition (see below). This means that with more than two elements, we only need to check pairwise complementarities: if all turn out to hold, the innovation function is super modular in those arguments.

Going directly to the definition, we may say that complementarity holds only if [b1+b2-b3-b4≥0], where b1 and b2 are the estimated parameter linked to "complementarities states", where two "factors/inputs" are either both present or both absent (i.e. (00), (11)), while b3 and b4 are associated with "substitution states", witnessing the presence of one factor only ((10), (01)). The reasoning, when revolving around couples of drivers (bivariate analysis), leads to a statistical framework where the hypothesis of complementarity is the one expressed above; a simple one sided t test is applicable and sufficient[9]. This is our "limited" focus in this paper.

In other words, complementarity holds if

(11) + (00) ≥ (01) + (10), where (11) is the state witnessing the presence of both factors (innovation drivers), and so on. It is more intuitive and correct to specify the above inequality as

(11) - (10) ≥ (01) - (00), that is the "incremental value" of a strategy that moves from one factor to two factors is, if complementarity characterises those specific factors, higher than the value of a strategy which adds one driver starting from the state (00). Theoretically speaking, the inequality is tested on a "non strict" basis (meaning ≥ instead of >)[10]. This point will be further addressed in the empirical part.

We argue that the value added of our analysis, though specific to an industrial region, is twofold: (i) we empirically study the issue of driver's relevancy and complementarity within the realm of environmental innovations in a multivariate framework where (ii) we exploit extended and recent survey based data on critical variables acting as drivers, which are rarely available in official datasets.

The sections below first discuss the dataset exploited and the context of reference; we then comment on on the main hypotheses associated with the aforementioned drivers, within the complementarities framework. We finally present results with regard to complementarity tests and we conclude with a summary and some policy issues.

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[9] We note that one-tailed tests make it easier to reject the null hypothesis when the alternative is true. A large sample, two-sided, 0.05 level t test needs a t statistic less than -1.96 to reject the null hypothesis of no difference in means. A one-sided test rejects the hypothesis for values of t less than -1.645. Therefore, a one-sided test is more likely to reject the null hypothesis when the difference is in the expected direction.

[10] Non strict complementarity may be associated with a sort of constant returns to scale, while strict complementarity directly points to an effective situation of increasing returns with regard to the analysed factors. This is plausible given that complementarity oriented factors may also be aimed at maintaining the current innovation dynamics, and thus performance. This is to be considered a successful outcome as well (Carlaw and Lipsey, 2002). We may affirm that strict complementarity relationships can be certainly associated with increasing returns to scale, generating extra rents and externalities with respect to the BAU scenario, but it is consistent also with constant returns to scale, where the market opportunity cost is merely replicated, and real externalities are not emerging

3. Data and context

We provide new evidence on the factors associated with 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 conducted on the same firms (2002 and 2004, eliciting data regarding respectively 1998-2001 and 2001-2004). It is worth noting that evidence based on firm level data possessing detailed richness and representativeness is quite rare for industry-based data since survey based approaches are the only option for data collection (Khanna and Anton, 2002; Lee and Alm, 2004).

We base our applied analysis on a district-based manufacturing local system in Emilia Romagna, Northern Italy. Emilia Romagna is an area of Northern Italy characterised by a high density of industrial districts, and shows a very high level of per capita GDP (around 27.000€ in 2003). Firms 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. The first survey carried out in 2002 was made up of a structured questionnaire administered to firm management by direct interviews. The investigation focused mainly on high-performance practices, industrial relations and technological/organisational innovations.

The survey on environmental issues was instead 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.1a-b, with respect to the population. 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[11]. Further, the adoption of environmental corporate management schemes was elicited. Three more questions elicited the expenses on environmental R&D, capital investments and direct costs (current costs plus tax payments, etc..) over 2001-2003. We refer the reader to table 2 for a general overview of descriptive statistics for main relevant variables used in the analysis.

On a descriptive basis, some notes on complementarities are possibly drawn out from the observation of count statistics. For example, taking R&D and auditing (tab.3), 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. With regard to 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 policy related costs do not show complementarity in both comparisons.

[11] The taxonomy of environmental realms is largely consistent with recent OECD studies (Darnall – Jolley – Ytterhus, 2005).

It is obvious that count statistics suggest only preliminary evidence on complementarities among innovation inputs. A full examination of complementarities by systematic multi-variate analysis is presented in the core section below.

4. Theory and empirical models

Here we comment on firstly on the main hypotheses related to the impact of drivers on innovation. Then, after a short methodological discussion on innovation modelling, we move to empirical results. Our empirical models set some below defined survey based innovation proxies as dependant variables. We first assess the main drivers of output innovations, then we test complementarity links along the lines discussed above.

4.1 A theoretical framework for environmental innovation drivers

We focus the analysis on four main drivers of environmental innovation: (i) policy actions (policy related costs); (ii) environmental R&D; (iii) eco-auditing schemes; (iv) networking activity.

The first step is to assess their correlation with innovation, when taken separately.

Then, the consequential but primary aim here is to verify whether the effect of such drivers on innovation is characterised by some sort of complementarity or, if otherwise, such drivers are substitutes in favouring innovations. We specifically want to test the complementarity between the voluntary auditing schemes with the policy-driven costs and the firm strategy on R&D. We are interested in assessing whether such EMS/ISO (broadly defined as bottom up and voluntary approaches which tackle environmental targets, are empty boxes or (i) are correlated to innovative strategies (R&D); (ii) are co-evolving with a policy-driven top down effect. This is crucial for informing environmental policies which operate on all sides: incentive R&D given potential market failures, supporting auditing for promoting environmental corporate effort and mitigating free riding behaviour in regional contexts, imposing additional costs through a diverse set of policies, typically taxes on emissions, energy use, and waste disposal. Further, we also test the complementarity between internal strategies (R&D) and externally driven factors (costs) in stimulating innovations[12].

We briefly comment on the role of policy, auditing, networking and R&D in our framework of research hypotheses.

[12] The division in external and internal factors driving EMS presented by McKeiver and Gadanne (2005) is similar to our investigation of internal (more endogenous) and external (exogenous) forces that may impact, separately or through complementarity links, on the adoption of technological innovation. They analyse market, legislation and local communities as external forces, and diverse management strategies and employee concerns as internal forces. All elements arise relevant factors in explaining auditing. This is coherent with the general outcomes arising from our multi driver's framework; we instead focus on the role of industrial relations (not employees) and policy related costs as main external drivers, and auditing and R&D as main internal drivers in the environmental side. Then, we investigate the role of non environmental variables.

Policy and policy related costs. The role of policies in stimulating innovation is a long debated issue at both theoretical and empirical level (Grubb and Ulph, 2002; Kemp, 1997; Krozer and Nentjes, 2006[13]). Given that official policy-related data do not exist at micro-firm level, survey data are consequently 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 (Requate and Unhold, 2003; Kemp, 1997). A candidate variable for representing policy action is the amount of policy related cost for policy implementation, net of expenses on safety and other compulsory job-related expenses. 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). We elicited information on direct environmental costs linked to current expenses and all financial burdens deriving from policies, excluding expenses for safety and security obligations, in order to take into account the aforementioned cost-related effect (ENV_COST). We elicited such expenses in terms of percentage of turnover to increase the reply ratio and ease respondents. In this paper we exploit the discrete data (presence or not), which may be more reliable and critical to some extent.

As other proxies of policy variables, having elicited whether emission and waste policies are being imposed to firms (policy "stringency" proxy), and for how many years firms have been subject to policies, we introduce 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[14].

Eco-Auditing schemes. We include auditing schemes for testing whether voluntary approaches (like EMAS, ISO14000) of environmental management improve, acting as a driver, the likelihood of introducing environmental related innovation (acronyms are *AUDIT* for the variable capturing the presence of either EMAS or ISO, and EMAS, ISO when included separately). Unlike ISO schemes, EMAS requires external communication via an environmental report. Environmental management systems are not widespread on average and in industrial districts as well[15]. Innovation intended as the adoption of (voluntary) auditing schemes (EMAS, ISO)[16] here concerns 26% of firms. With

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[13] The first paper deals with mainstream models of innovations stimulated by Policies, the second contribution extends the reasoning to more dynamic non mainstream frameworks. The latter one presents an investigation of the interdependencies of policy and innovation cycles.

[14] We stress that the use of survey data is the only option, given that policy-related variables/innovation are not generally available for SMEs (and even larger firms). SMEs are in addition not subject to main national/EU policies (e.g. EU ETS), but to the fragmented regional policies on environmental objectives.

[15] 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, the ceramic district in Emilia Romagna was the first to get EMAS certification.

[16] Schemes 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

regard to the link between environmental innovation and auditing schemes we note the recent applied oriented contributions by Horbach (2003) and Frondel et al. (2004) and Rennings et al. (2003). Although most of the literature emphasises the potential role of voluntary eco-auditing schemes as innovation drivers, the issue still remains debated. For example, Dosi and Moretto (2001) suggest that eco-labelling may also induce perverse effects, such as increased investments in conventional technologies (more polluting with respect to new technologies) before the label is awarded[17].

Environmental R&D. Turning our attention to environmental R&D, the link between R&D and innovative output is the usual one tested in the literature. In our case it is of interest that we analyse R&D relationships with auditing and costs and that we possess data with regard to environmental R&D (for example, even Jaffe and Palmer (1997) use R&D as driver of environmental innovation. An alternative (correlated) driver, environmental capital investments (ENV-INV) is also tested. At the level of complementarity we focus on the more specific role of R&D. The two terms are in any case highly correlated.

Networking. We note that networking activities may partially substitute economies of scale in environment characterised by small and medium firms. We elicited data on the source of environmental innovation, including networking with other firms and public institutions, to test an important hypothesis which recently emerged from the "social capital (SC) literature" (Glaeser - Laibson - Sacerdote, 2002): the positive relationship between R&D and social capital in an impure public goods framework (Cornes and Sandler, 1997), where social capital arises as intangible asset, defined as firm investments in co-operative/networking agreements. Cainelli et al. (2005, 2007) and Mancinelli and Mazzanti (2004) theoretically and empirically analyse the link between R&D and networking/ social capital. Within a theoretical framework that considers social capital as the public component of the impure public good R&D they claim that the 'civic culture' of the district area in which a firm works is not a sufficient incentive to increase its investment in SC. Social capital/networking dynamics might positively and complementarily evolve only if the opportunity cost of investing in innovation is sufficiently low. When empirical evidence confirms that this complementarity plays a key role, the policy effort should be targeted toward both market and non-

reduction and implementing plans to 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 - Anton, 2002, p.541).

[17] The hypothesis of eco-auditing being a driver of environmental innovations and complementary to more formal R&D investments relies around the commitment to continuous improvement that might not be over with EMS registration or ISO certification. This is more likely if it occurs that the willingness to obtain competitive advantage and satisfying new customer needs overweight the need to simply comply with a non economic but management oriented, thus to some extent softly incentive-based, tool. Biondi et al (2000) find that all three aforementioned factors are drivers of EMS. We claim that the more mere compliance is relevant, the less such schemes could arise as complements to core environmental innovations and consequently firm performances at overall or specific environmental level.

market characteristics, rather than solely to the production of local public goods or innovation inputs as independent elements of firm performances. The difference is important as far as policy effectiveness is concerned.

As underlined by Biondi et al. (2000) for SMEs, communicating and interacting with other public and private agents is an important part of the process when implementing EMS, in order to reduce fixed and transaction costs. Though it is not here the core of the analysis, an important idiosyncratic role may be played by industrial relations. 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). To our knowledge the link between industrial relations and environmental innovation strategies has very rarely been tested[18]. 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[19]. 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 (Addison and Belfield, 2001) and their generalisation would not be granted[20].

Finally, exploiting trends for high-performance practices/organisational innovation and process/product innovation in 1998-2001, we also test and control whether environmental innovations are 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., 1995). The link between techno-organisational innovation and environmental innovation has never been tested to our knowledge[21]. We test diverse proxies: (i) 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); (ii) another proxy of organisational innovation is the flatness of the organisational structure: it has been argued that flatter organizations perform better

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[18] Frondel et al. (2003) provide some evidence on the effect of unions as a "pressure group", finding ambiguous evidence.

[19] Our main indicator, ranging between 0 and 1 to represent intensity and quality of management/trade unions/employee relationships with regard to firm strategies, is a synthetic index of industrial relations "intensity" with regard to 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 managers/workers joint work groups, employee participation in formal structures with decisional power.

[20] 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 (Valenduc, 2001).

[21] Florida et al. (2001) analyse the relationship between organizational resources/organizational innovativeness and EMS schemes, exploiting firm-level data, finding a positive correlation.

in terms of innovative dynamics, compared to more "centralized" firms. 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)[22].

Thus, when analysing innovation drivers we verify the role played by industrial relations and techno-organisational innovations, such as TQM, process/product innovation adoptions, hierarchical structure[23].

We also control all specifications by entering firm structural variables. Economies of scale may spur innovative strategies and reduce the cost burden: either/both of the largest firms may bear the fixed costs of investing in innovation. We use the number of firm employees as size proxy (including linear and squared terms). Additional control variables are 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). Finally, a dummy capturing the membership of national or international industrial groups is also used as control, and may capture dimensional effects (GROUP). A full list of variable description, including acronyms, is presented in table 2.

4.2 Methodological issues in modelling innovation

There is no shared model for studying innovation determinants both at industry and firm level. It is 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, even when we may rely on patent data.

It is worth noting that in our case study, the share of firms reporting an environmental-related patent activity is very low (2%). Though the outcome is compatible with the historically low number of patents produced by Italian firms (with the exception of the machinery 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 with

[22] Hierarchical intensity structure is defined as the ratio of the number hierarchical layers on the number of formalised firm divisions (fifteen specified).

[23] Given the scope of the paper is mainly on complementarity links we here just mention this result. A general outcome of our empirical analysis is that "non environmental" techno-organisational innovations are not correlated to adoptions of main environmental innovations. This is somewhat in contrast to other recent evidence in the field (Rothenberg and Ziglydoupolous, 2006; Henriques and Sadorsky, 2006); in any case our results are rooted on data that derive from different surveys focusing respectively on general innovations and eco innovations. We argue then that this evidence is robust and may indicate that firms are (not yet) integrating environmental innovations in process/product processes, maybe exploiting end of pipe rather than integrated process strategies in the environmental field. We focused the analysis on different environmental innovation "fields" rather than on the end of pipe/process integrated framework, which is certainly a relevant objective of research (Frondel et al., 2006; Rennings et al., 2004; Rennings, 2000).

regard to 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 on by Gu and Tang (2004), who stress that some firms protect property rights by trade secrets and copyrights instead of patenting. Complementarity, as observed in the conceptual section, might be an informal way of protecting innovation rents by creating intangible idiosyncratic links between inputs.

In order to perform the estimation of an objective innovation function to develop tests for complementarity, 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 of a production function. The reduced form is as follows:

(1) $INN_{i,t} = \beta_0 + \beta_{1,t}$*(structural firm features)* $+ \beta_{2,t}$*(environmental R&D)* $+ \beta_{3,t}$*(eco-auditing)* $+ \beta_{4,t}$*(policy related policy costs)* $+ \beta_{5,t}$*(innovation networking)* $+ \beta_{6,t}$*(environmental policy proxies)* $+ \beta_{7,t}$*(techno-organisational innovation)* $+ \beta_{8,t-1}$*(industrial relations)* $+ \beta_{9,t-1}$*(past performances)* $+ e_i$

Where INN_i represents the environmental innovation output of firm i, and e_i the error term with usual properties. B_0 is the constant term, β_{1-8} the set of coefficients associated with explanatory variables (β_{2-5} being the core set of drivers). (t) stays for 2003-2001 and (t-1) for 2001-1998.

As proxies of output innovations, we use INNO-EM (adoption of process/product environmental innovation related to emissions), INNO-WA (adoption of process/product environmental innovation related to waste), and INNO-EN (adoption of process/product environmental innovation related to energy inputs)[24]. Those are dummies. Then, we also exploit INNO-TOT (synthetic index of the adoption of the four environmental innovation, including reduction in the use of input materials).

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 that there is not an "optimal" econometric model for studying fractional variables. It is possible to verify that estimates deriving from OLS, OLS based on (log) transformations (when this is possible given the observed "0s") and Tobit-like 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

[24] We do not exploit the dummy variable representing adoptions of any innovation, since 80% of firms do it. Material related innovation is instead not used due to poor statistical fit in preliminary regressions.

(here) the estimation of elasticity, this may be considered a less severe flaw. Thus, OLS corrected for heteroskedasticity is used as an econometric tool for estimation.

When testing complementarities between innovation outputs, instead, a bivariate probit model is exploited, which specifies a joint distribution for two regressions. The null hypothesis of no correlation is used as a test for complementarity. If rejected, complementarity holds between the two innovation outputs. In brief, the bivariate probit is employed when one wants to test the hypothesis of inter-relationship between two key dependent variables. The use of separate binary equations for diverse innovation activities could lead to distortions in estimates given the potential correlation between the two error terms.

5. Environmental innovation: drivers and complementarity relationships

This section presents the main results of the empirical study. We first present results with regard to the analysis of innovation drivers, which is aimed at drawing out the main significant among these, and consequently discuss the core examination of complementarity relationships at input and output level.

5.1 Preliminary tests

Given that innovations, R&D, environmental costs and auditing schemes are all elicited 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 innovation-performances links, which are intrinsically subject to the reverse causality conceptual problem. In fact, R&D and costs are conceptually inputs, auditing schemes may be correlated to but hardly "explained" by innovations. Nevertheless, endogeneity is properly tested by a Wu-Hausman test (Woolridge, 2002, p.118-20)[25]. 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 factor most likely to present endogeneity problems in those cases [26]. We then introduce the associated fitted values as a further two-stage estimation attempt in

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[25] 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 exogenous structural variables (controls), 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 exogeneity, and as a consequence IV estimation is not needed. 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 (Woolridge, 2002, pp.90-93).

[26] See in fact Pickman (1998) who analyses the relationship between abatement costs and patented innovation, finding a positive coefficient, but correcting for endogeneity given observed correlation between

this case (Millock and Nauges, 2005). 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.

5.2 Examining the drivers of Environmental Innovation

We comment on the following outcomes deriving first (i) from binary probit analysis, when disaggregating by "environmental innovation issues"[27], and (ii) from estimations carried out on synthetic index of environmental innovation. A preliminary analysis was carried out to study the full correlation matrix, concerning all potential covariates, in order to drop high-correlated potential regressors. This first selection is aimed at reducing collinearity problems. The outcome is a matrix of *selected* potential explanatory variables[28].

First, environmental innovation with regard to emission-reduction results as being positively influenced by the presence of voluntary auditing schemes. With regard to policy-related explanatory factors, we note that the (reported) presence of emission-policy related 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 explanation may be that we observe 2001-2003 innovations, thus most firms might have previously adopted innovations, based on policies, our innovative firms may be the "newcomers" (in relative terms). The positive effect of R&D arises only when specifying a dummy variable as explanatory factor (R&D/employees instead is not significant, and neither are environmental costs[29] and investments). Size and sector controls do not influence adoption. The index of "participative innovation oriented" industrial relations is a positive driver.

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,

costs and unobserved variables. Endogeneity is here also caused by potential co-causation (Wooldridge, 2002).

[27] See table 4 for a summary of main outcomes.

[28] Not presented for brevity, available on request. Overall, correlation problems are of limited relevancy here.

[29] Predicted values of costs are included, but they do not result as being 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 significant here. Then, policy effects may also pass through the positive influence of environmental costs, which are moderately significant. Nevertheless, we note that though the Wu test highlighted potential endogeneity, even for waste, the fitted values are not significant. Waste innovation also shows itself to be positively influenced by the presence of voluntary auditing schemes and by a flatter organisational structure. Size is still not significant, with group membership dominating over firm size effects, some sector influence emerges (ceramic).

Thirdly, turning to innovation in the realm of energy efficiency, we observe that R&D is significant among the 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. Industrial relations dynamics confirm their already noted positive effects.

Finally, we examine the 0-1 continuous index capturing all realms of innovation (INNO-TOT). OLS corrected estimates show (tab.4, last columns) that (i) R&D and costs are significant while investments are not (regression 4); (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 ISO_{14000}). 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 already mentioned evidence, 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 in decisional processes on high-performance and organisational strategies. Past performances prove not to influence environmental innovation.

The analysis has shown that all hypothesised main drivers affect environmental innovations. Building on such premises, we now move to the specific investigation of complementarity.

5.3 Innovation output: bivariate probit analysis

As a first point of analysis within the complementarity environment, on the output side, a bivariate probit analysis is carried out to test the correlation between various environmental innovations (tab 5.1 presents correlation values of different regressions). The adoption of emission reduction technology is correlated to the adoption of both waste and energy oriented technologies. Emission reduction arises thus plausibly as a leading strategy, coherently and expectedly linked with energy saving technologies, but also with waste oriented strategies. The underlying reason may be that higher waste management efficiencies strengthen or add to emission strategies. The more materials flows are reused and re-integrated within firm productive processes, the less emitting may be the overall process. The other reason could be that emission and waste management/disposal are, at Italian and EU level, two relevant targets of policies. The observed correlation could also be a response to more prominent policy stimulus in those areas. The lack of correlation between emissions and material strategies may be a signal of the fact that end of pipe and at source objectives are not yet integrated within a common firm environmental planning.

Waste processes are also correlated with material input reduction strategies; this confirms a quite clear cut expectation, being waste management strategies a complement to reduction in material flows entering the process, while this occurs for energy saving and material saving, both placed at the source of the productive chain. Finally, we note that waste and energy do not correlated regarding innovation adoptions. The reason is probably one linked to the absence of an integrated process, again, which sets up waste-related energy saving investments, like bio-mass/waste recovery by incineration, at the SMEs firm level.

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 are pursued by a limited number of innovative firms which are more committed on all environmental grounds. When firms become "environmental innovation adopters" they tend to pursue an integrated strategy covering diverse fields on the green oriented arena. On this basis, let us instead analyse the degree of complementarity between the drivers of such innovation outputs.

5.4 Input complementarities: R&D, auditing and policy related costs

This section presents applied results for complementarity tests. Regarding the objective function, regressions are estimated both for specific dichotomous innovation proxies (i.e. energy, emission, waste) and for the total index of innovation intensity. All regressions include control variables. In order to further test the robustness of results, we include additional covariates, which resulted significant from regression analysis (par. 4.3), to verify the sensitivity of results to potential omitted elements.

In order to carry out bivariate tests on innovation input complementarities, we first specify regressions entering the four dummies associated with the potential states of the world for each bivariate case: 00, 01, 10, 11. All coefficients related to state dummies have to be estimated; the model is thus a specification without constant (dummies statistically enter as constants), instrumental to estimate the parameters for carrying out the test. In additions to those states, control variables are included. We recall that in a bivariate framework we need to test a single hypothesis of the form [$b1+b2-b3-b4\geq0$][30], where b1 and b2 are the estimated parameters linked to

[30] Theoretically, the hypothesis specified in terms of ≥0 is the usual one we found in most relevant theoretical contributions on super modularity and complementarity (Topkis, 1978, Amir, 2005, among the others). This

"complementarities states" (i.e. (00), (11)), while b3 and b4 are associated with "substitution states" ((10), (01)). A one-sided t test is sufficient when the reasoning collapses to a single hypothesis, when n=2. The null hypothesis is the complementarity state under a non strict inequality (≥0)[31]. Thus, the framework is defined by four states of the world combinations and one non trivial hypothesis for verifying complementarity, for each of the (three) couples separately. It is worth noting that complementarity is eventually proved only with regard to each specific couple, case by case.

Estimates and consequential test analysis show that the complementarity hypothesis holds in most cases (tab.5.2). We nevertheless note that ENV-COST is particularly associated with negative signs of the test; but only in one case (R&D-ENV-COST for the emission-related innovation specification) the t value leads neatly to a rejection of the null. R&D and policy related costs seem to be thus substitutes drivers in this specific context, claiming for the use of one "driver" only[32]. We also observe that the only case where complementarity would hold even in a strict sense (>0) is that regarding AUDIT - R&D, in the adoption of energy saving innovations. AUDIT and R&D relationship signals an interesting complementarity, often debated at conceptual level, between organisational and technological innovation at the firm input level. Taking the overall picture, we may observe that complementarity, defined as above, holds for most specifications, but one. We note that while when taking the overall index of innovation adoption complementarity holds, when we analyse more in depth the picture more heterogeneous results arise.

Entering additional explanatory elements (firm hierarchical intensity, industrial relation index, other techno-organisational innovations, etc..) the picture does not change with respect to complementarity tests. Results are thus note sensitive to the inclusion of additional covariates, though some (see also par.5.2) are statistically significant and improve the fit of the regression with respect to the base specifications with states and controls only.

To sum up, the analysis first confirms the need to carefully verify the occurrence of the probably "abused" concept of complementarity in each specific contingent case under scrutiny (case study, innovation, drivers, etc..), and secondly highlights that, in our framework, the main envisaged drivers of environmental innovation, R&D, policy related costs and auditing, are characterised by a framework where complementarities are relevant.

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means that complementarity holds even when the "net sum" of parameters we test "tends" to zero. Statistically, if we specify the null imposing ≥0, we reject it when only the drivers are clear substitutes.

[31] More specifically, in this case we have three possible outcomes: if the null is not rejected the hypothesis of complementarity holds in the ≥0 form, which is consistent with the theory. A value higher than 1.645 on the positive sign will lead to a strict complementarity assessment (b1+b2-b3-b4 >0), it would be like rejecting the null b1+b2-b3-b4 ≤ 0, while a negative value lower than the defined threshold (e.g. 1,645, or a 5% tail, within the one tail framework) will lead to a rejection of the null.

[32] It means that, for instance, R&D subsidies and environmental taxes are probably (and plausibly) conflicting factors in this field.

5.5 R&D and networking

The link between R&D and networking deserves a separate comment (tab.5.2). The complementarity hypothesis recently emerged from the literature dealing with innovation, social capital as networking and spillovers occurring in local district systems. We test this specific hypothesis on the basis of the comment on the above discussed (§4.1) stream of research on techno-organisational innovation and networking. Further works could also investigate the links between organisational innovations such EMS and networking.

Tab. 5b presents results in last columns. They do not seem to provide a clear message in favour of complementarity. Polar cases emerge. When considering the total index of innovations, the test provides strict complementarity evidence when also policy related costs and auditing are included as covariates, otherwise when only controls are included, substitution emerges. Thus, the outcome is not completely robust to a sensitivity analysis on the vector of independent variables. As far as emission innovation and energy saving innovation are concerned, complementarity holds. With regard to waste, the same outcome observed with the synthetic index of innovation emerges. The evidence is thus mixed: in two innovation cases (EM/EN) complementarity holds on a non strict basis, independently on the included covariates; in the other two cases, the synthetic index and waste, strict complementarity or substitution emerges as outcomes, depending on which specification is chosen. Provided that specifications with additional covariates are more robust in statistical terms complementarity signals may be greater than substitution signals all in all. R&D and networking are thus complementary assets reinforcing each other in a virtuous (or vicious) circle in SMEs dense local environments.

We observe that although our analysis shows and probably confirms a hypothesis of complementarity between drivers, this generally emerges in a non strict way. We also find cases where such main drivers are not complementary. Further research will test complementarities relationships taking into account vector of three drivers and not only couples, in the discrete framework here set.

6. Conclusions

The aim of this paper is twofold. It provides new empirical evidence on the drivers of environmental-linked innovation at a microeconomic level. Secondly, following this base empirical evidence, we consequently test complementarity relationships characterising on the one hand main innovation drivers and on the other hand innovation output adoptions.

We exploit recent and rich survey-based data covering many potential innovation-related factors. The paper adds new evidence focusing on the environmental performance at firm level in a framework where SMEs prevail. Environmental innovation dynamics are a proper field for analysing the complexity of innovation dynamics, within which management strategies and policy action interact.

Summing up on emerging innovation drivers, voluntary eco-auditing schemes appear to play a strong role in favouring innovation output dynamics. Environmental specific R&D, the reshaping of organization structures and the industrial relationships along more flexible and innovative scenarios, and policy-related costs may all bring about environmental innovations, impacting on firm strategies and firm behaviour. Structural firm variables appear to matter less than the aforementioned drivers. The extended multivariate analysis shows the joint importance of exogenous and endogenous firm-related drivers in complex industrials settings, where policy actions, firm behaviour and the territorial involvement of social parties are all relevant in explaining and favouring eco-innovation dynamics.

Building on this, with regard to the analysis of complementarity our results show that the hypothesis of complementarity generally holds. As far as innovation outputs are concerned, the correlation analysis shows that firms which do innovate tend to pursue different environmental innovations jointly, at least for our categorisation sub-dividing innovations in waste-related, emission related, material related and energy related innovations. The correlations arising statistically significant provide food for a plausible interpretation of results, as comment on. Emission reduction arises thus plausibly as a leading strategy, coherently and expectedly linked with energy saving technologies, but also with waste oriented strategies. The reason could be that emission and waste management/disposal are, at Italian and EU level, two relevant targets of policies. Waste processes are correlated with material input reduction strategies, while the lack of correlation between emissions and material strategies may be a signal of the fact that end of pipe and at source objectives are not yet integrated within a common firm environmental planning.

At the level of innovation drivers, we observe that the complementarity link, though predominant across the various analysed couples of drivers, is associated with more heterogeneous evidence. While it is always valid for the total synthetic index of environmental innovations (intensity of innovation), this is not true for some specific innovation adoption. Among the other results, it is worth noting that R&D and environmental costs emerge as substitutes for emissions innovations while auditing and R&D presents strong complementarity evidence. With regard to R&D and networking, the picture generally confirms the hypotheses of complementarity, as expected by theoretical considerations.

Thus, although our analysis supports an hypothesis of correlation/complementarity between drivers, we also find cases where such main drivers, policy related costs, R&D, networking and auditing, are not complementary. This kind of analysis is extremely relevant for feeding policy making at the level of firms or districts.

Complementarity then supports innovative dynamics, but it is not to be considered the panacea for managing complex situations where multiple externalities are present. The validation of the hypothesis, on a strict or non strict sense, depends upon the drivers considered, the industrial environment, the local production system under scrutiny. Our results shed light on environmental innovation in a local manufacturing sector. They nevertheless open space for new research in the field, allowing some generalisation circumscribed to the features of our case study.

Implications may be the following. If complementarity holds, evidence points towards the need of policy integration (i.e. innovation, certification and strict environmental policy, etc..). Integration within the more circumscribed environmental field or more extensively, including environmental aims in other policy areas. Complementarity generates increasing returns from the implementation of two or more managerial and /or policy efforts. Thus, strong complementarity could generate efficiency saving: increasing returns of scale could allow the achievement of the same (innovative) targets with less effort. Our evidence does not generally supports a "strong" complementarity framework. Nevertheless, even a scenario where complementarity exists in a "non strict" form (constant returns) is favourable, supporting the implementation of multiple drivers.

Substitutability may instead signify that policy efforts or managerial and policy efforts are in conflict with each other, generating negative spillovers: we may choose the most effective among these. We thus observe the relevancy of complementarity assessment at both policy and management level. For example, policy may undermine firm strategies in some ways, or the other way round: ins some contingent cases the interaction of drivers may have negative effects on innovation. As another example, it is for example claimed in the policy arena that sometimes too many policy drivers stimulate innovation: efficiency and effectiveness of actions could be undermined if complementarity does not hold.

Our analysis suggests that, though policy actions may benefit from analysing potential complementarities, economies of scale, cross effects and externalities may not be so easily grasped and common even in intense innovative environments. With regard to firm management, complementarity of technological and organisational elements helps firms to reap some increasing returns, though this is highly dependent on the type of environmental innovation and on the couples of drivers we focus on. Complementarity, though important from a policy and managerial perspective, is then probably not the all inclusive panacea for tackling and solving the complexity of innovation dynamics, both from the management and the policy action sides.

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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. 2- Dependent and independent variables uses in the analyses: descriptive statistics

Main Indicator variables	Type	Mean value	Maximum value	Minimum value	Acronym (for variables used in regressions)	Notes
Adoption of any environmental innovation	Dichotomous 0/1	0,79	1	0		It captures the adoption of at least one of the four specified innovation types
Adoption of emission reduction related innovations	Dichotomous 0/1	0,49	1	0	INNO-EM	It captures the adoption of emission related innovation only
Adoption of waste management related innovations	Dichotomous 0/1	0,42	1	0	INNO-WA	It captures the adoption of waste related innovation only
Adoption of energy reduction related innovations	Dichotomous 0/1	0,46	1	0	INNO-EN	It captures the adoption of energy related innovation only
Adoption of material input reduction related innovations	Dichotomous 0/1	0,27	1	0	INNO-MA	It captures the adoption of material related innovation only
Synthetic index of the adoption of environmental innovations	Ranging between 0-1	0,41	1	0	INNO-TOT	It captures the adoption of the four forms of innovation
Environmental R&D	% turnover, all firms*	0,55%	10%	0%	R&D	Environmentally oriented R&D expenses per employee
Environmental R&D(2)	Dichotomous 0/1			0	R&D dummy	Positive R&D expenses
Environmental Investments	% turnover, all firms*	0,78%	10%	0%	ENV-INV	Environmental capital investments per employee
Environmental policy costs	% turnover, all firms*	0,67%	16%	0%	ENV-COST	direct environmental costs linked to current expenses and all financial burdens deriving from policies, excluding expenses for safety and security obligations, in order to take into account the aforementioned cost-related effect, per employee
Environmental Patents	Dichotomous 0/1	0,02	1	0		Patented innovation over the period
Auditing voluntary certification Schemes (EMS or $ISO_{14000, 9000}$)	Dichotomous 0/1	0,26	1	0	AUDIT	Dummy variable: value 1 if auditing schemes adopted
EMS, ISO_{14000}	Dichotomous 0/1	0,042; 0,12	1	0	EMAS, ISO_{14000}	Dummy variable: value 1 if specific EMAS or ISO schemes adopted
Networking index	Ranging between 0-1	0,18	1	0	NETW	Index capturing networking activities with other firms and research institutes with regard to the four innovation realms
Firm size	Continuous	4,94	8	3,91	Log-Size	Logarithm of employees
Sectors	Dichotomous 0/1	0,07;0,54;0,23	1	0	CHEM, MACH, CERAM	Dummy variables: value 1 if belonging to chemical, machinery, ceramic sector
Group membership	Dichotomous 0/1	0,31	1	0	GROUP	Dummy: value 1 if belonging to industrial groups
Hierarchical structure of the firm	Ranging between 0-1	0,29	1	0,13	HYER	Index of firm hierarchical levels on firm functions (hierarchy ratio)
Industrial relations	Ranging between 0-1	0,32	0,87	0	IND_REL	It represents intensity and quality of management/trade unions/employee relationships. 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
Compliance to a policy	Dichotomous	0,66;0,70	1	0	POL-WA/EM	Dummy; value 1 if the

on waste / emissions	0/1					firm has been subjected to policy (waste / emissions)
Years of Compliance to a policy on waste / emissions	Continuous	7,40;8,8	25;27	0	POL- WA/EM (YRS)	(log) number of years since the policy was introduced
Environmental grants received over the period	Dichotomous 0/1	0,05	1	0	GRANT	Dummy, value 1 if a firm has exploited a public grant for innovation purposes
Log of value added	Continuous	4,5	6,6	3,8	$PROD_{9800}$	Firm productivity average level 1998-2001 (from balance sheets)

*including all firms, with positive and zero values.

Tab. 3- Occurrence of innovation inputs states (Auditing, R&D, policy related costs)

000	111	001	011	100	110	010	101
No input	All inputs	Policy related costs	R&D and policy related costs	Auditing schemes	Auditing schemes and R&D	R&D	Auditing schemes and policy related 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 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. 4- 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. the EMAS factor drives the significance of the variable 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.5.1- 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. 5.2- bivariate complementarity tests

	Auditing/R&D	Auditing/ ENV-COST	R&D/ ENV-COST	R&D/networking
INNOTOT	0,18	-0,63	-0,18	-1.93/2.33[33]
INNOEM	0,19	-1,35	-2.00	-0.33/0.52
INNOWAS	-0,58	-0,84	1,05	-2.83/2.80
INNOEN	2,14	0,49	-0,24	0.10/1.10

Values of the T test (one sided t test) shown.

Tab.6 – Main recent empirical contributions dealing with complementarity

Paper	Performance	Innovation activities on which complementarity is tested	Data/country
Caroli, van Reenen (2001)	PRODUCTIVITY	Skill, organisational innovation/change	Panel/UK
Bresnahan, Brynjolfsson, Hitt (2002); Brynjolfsson, Hitt, Yang (2002); Brynjolfsson, Hitt (1997, 2000, 2003)	PRODUCTIVITY	HRM, organisational innovation/change, skill, ICT	Panel/US
Laursen, Mahnke (2001)	*	High performance practices, HRM	Cross section/Denmark
Laursen, Foss (2003)	Product and process innovation	Organisational innovation/change, HRM	Cross section/ Denmark
Lokshin, Carree, Belderbos (2004)	PRODUCTIVITY	Techno-organisational innovation/change; R&D networking	Cross section/Netherlands
Galia, Legros (2004a)	Product and process innovation	Team work, training, HRM, organisational innovation/change	Cross section/France
Galia, Legros (2004b)	*	Innovation obstacles	Cross section/France
Guidetti, Mancinelli, Mazzanti (2006)	PRODUCTIVITY	General and specific training	Cross section/Italy
Cristini, Gaj, Leoni (2004)	PRODUCTIVITY	Organisational innovation/change, ICT	Cross section/Italy
Astebro, Colombo, Seri (2005)	PRODUCTIVITY	Automative technological technologies	Cross section/US
Mohnen, Roller (2005)	Innovation	Innovation obstacles	Cross section/ EU
Aral, Weill (2005)	PRODUCTIVITY	HRM, organisational innovation/change, skill, ICT	Panel/US

*the analysis sees hypothesised complementary variables as dependant variables in the model, not drivers of firm performance.

[33] The two values refer to first base specifications using the control vector and then specification with also auditing and policy costs. We note that in probit regression the (0,0) state of the world is significant associated with a negative coefficient, and conversely the (1,1) case to a positive coefficient. Thus, complementarity is probably not emerging given the higher statistical significance of the negative sign relatively to the positive but not highly significant (11) state of the world.