

Complementarities, Firm strategy and Environmental Innovations

Empirical evidence for the manufacturing sector

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Abstract

Innovation is a key factor for achieving a better environmental performance of firms, to the extent that helps increasing the material/energy efficiency of production processes and reducing emission/effluents associated to outputs. The scope of the paper is twofold. First, new evidence is provided by testing a set of hypothesis, concerning the influence of a wide array of innovation drivers. Secondly, we analyse the hypothesis of a complementarily relationship concerning different environmental innovation outputs (energy, emission, waste) and concerning innovation drivers, such as R&D, policy induced costs, auditing schemes and networking firm activity using a discrete based framework.

The applied investigation shows that usual structural characteristics of the firm and performances appear to matter less than R&D, induced costs, organisational flatness and innovative oriented industrial relations. Complementarity is strongly emerging concerning innovation outputs. As far as input complementarities are concerned, we observe that the existence of a strong complementarity link is sensible on the typology of innovation and on the investigated drivers. Evidence show that also substitutability cannot be excluded for some couples of inputs. Concerning firm management, complementarity of technological and organisational elements helps firms to reap some increasing returns, though this is highly dependant on the type of environmental innovation and on the drivers we focus on. Our evidence shows that though relevant for explaining innovation dynamics, 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, induced 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. 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 area¹. 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 spillovers 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.

The scope of the paper is manifold. First, new evidence is provided by testing a set of hypothesis, concerning the influence of: (i) firm structural variables; (ii) environmental R&D; (iii) environmental regulatory costs; (iv) past firm performances; (v) other non-environmental techno-organizational innovations and (vi) quality/nature of industrial relations. Secondly, we analyse the hypothesis of a complementarily relationship concerning innovation drivers using a discrete based framework. Selected drivers are R&D, policy induced costs and auditing schemes. As environmental output innovation proxies, we use both three binary indexes for the adoption of innovations concerning waste, energy and emissions, and a synthetic index of innovation intensity. Third, a test of complementarity between different output innovation choices is carried out.

The primary aim is to test the complementarity between the voluntary auditing schemes with the policy-driven induced 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

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”.

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. Complementarity is analysed in a discrete environment: the presence/absence of drivers is critical for assessing the impact on innovation.

2. Environmental innovations, innovation drivers and complementarities

The empirical analysis of input complementarity in the 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.

Concerning the evidence on environmental innovation, 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.

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. Other contributions are Cole et al. (2005), Greenstone (2004), Magat and Viscusi (1990), Gray and Shabdegian (1995), Greenstone (2001), Darnall et al. (2005), Konar and Cohen (2001), Brunnermeier and Levinson (2004) and Gray (1997). Recent studies also use micro-simulation models of industrial dynamics simulation to explore the extent to which the dynamics of environmental innovations developed by firms are potentially integrated to the whole innovative and productive process, and respond to environmental regulations (Otra and Saint Jean, 2005).

Turning to the specific issue of complementarity, it has been addressed both from a theoretical and empirical perspective over the past ten years, taking both main stream and heterodox approaches into account. A critical survey of the literature is not the aim of the paper³.

The relevancy of complementarity among drivers of performances has been underlined by works within the wide 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 for this approach and for 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 concerning diverse factor affecting firm performance such as technological innovation, R&D, organisational innovations, high performance practise, training (Becker and Huselid, 1998). Various hypotheses of complementarity are explored, both with respect their effects on firm performance (productivity, profits) and regarding innovation performances (Pini, 2006).

³ Tab. 6 sums up main recent empirical contributions on complementarity.

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. An 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 dependant 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).

The third approach is the one which allows a greater flexibility and it is the currently the most widespread. We may call it the productivity approach: it can deal with two or more factors on which the hypothesis is tested, and it is based on the estimated of an objective function, either a production function or an innovation function. Within it, two ways are possibly 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 most 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 to complementarity or substitutability.

As far as empirical analysis is concerned, complementarity is analysed both by mainstream approach exploiting production function framing, or by less orthodox models like innovation functions or empirical model using as dependant variables productivity or other firm performances. It is worth noting that all those approaches, more or less mainstream, try to verify causal links between input and output variables. 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 to the joint asset specificity of some inputs and innovations, which may produce idiosyncratic not replicable organisational framework, leading to higher performance and rents. Other works which address the issue in heterodox environments, mainly using case study analysis or simulation approaches, are among the others, Langlois (2000), Kaufmann et al. (2000), Marengo and Dosi (2005). Complementarity is nevertheless addressed and studied from a quite radically different angle, with a conceptual focus on technological uncertainty, systemic evolution, and dynamic capabilities of firms. The assessment of causal links between input and output variables is not the aim of such various streams of research.

Summing up, the present paper focuses on the complementarities of innovation drivers in a discrete setting, taking as main reference the first and third approach listed above; within the latter, we implement 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). given a set of n drivers, complementarity holds in a discrete setting whenever the whole is more than the sum of its parts. In a standard framework, complementarity between a set of variables means, formally, that the cross partial derivatives of the objective function are positive⁴. 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”.

2.2 Testing complementarity

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 complementarily relationships concerning innovation drivers. Selected drivers are R&D, policy induced costs, auditing schemes and networking form activity

Some more words on the discrete framework are necessary. In order to pursue the analysis on 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 components. We add that in the discrete setting, it is sufficient to test pair wise complementarity. Then, the function is super modular over a (chosen) subset of its arguments, if and only if all pair wise elements are satisfying the complementarity definition (see below). This means that with more than two elements, we only need to check pair wise complementarities: if all turn out to hold, the innovation function is super modular in those arguments. With only two inputs, we collapse to a case of just two arguments and one pair wise analysis of drivers.

Going directly to the definition, we may say that complementarity holds only if $[b_1 + b_2 - b_3 - b_4 \geq 0]$, where b_1 and b_2 are the estimated parameter linked to “complementarities states” (i.e. (00),

⁴ 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.

(11)), while b3 and b4 are associated to “substitution states” ((10), (01))⁵. The reasoning, when revolving around couples of drivers (bivariate analysis), leads to a statistical framework where the complementarity’s hypothesis is the one expressed above; a simple one sided t test is applicable and sufficient⁶. This is our “limited” focus in this paper.

More generally, when reasoning around the complementarities characterising three drivers together, statistical analysis enters the realm of joint inequality tests (Kodde and Palm, 1986; Mohnen and Roller, 2005). It is necessary to test a set of joint hypotheses deriving from the (increased) potential combinations. As said, the three dichotomous drivers generate a set of potential combinations, technically 2^n ($n=3$ in our case). Tab. 3 presents the 8 states and their statistical distribution in our case study.

For example, focusing on drivers 1 and 2, taking 3 as fixed, the hypothesis to test is in this case the following. Complementarity holds when both

$$(000) + (110) > (010) + (100) \quad \text{and}$$

$$(001) + (111) > (011) + (101) \quad \text{hold}$$

It is worth noting that it is sufficient to verify complementarity by couples; then, the object function is super modular (fully complementary) in its selected arguments if and only if complementarity holds for the three (in our case) joint set of hypotheses (1-2, 1-3, 2-3).

We above drew out the states for the couple of drivers 1-2. The same reasoning applies to couple (1, 2) and (2, 3)⁷. Only if the all set of inequalities holds (three joint tests), then we may affirm that the function is super modular with respect to the specified drivers (drivers are complementary in determining innovation).

⁵ This for the simpler case of two inputs or couples of inputs analysis. With three drivers, for example, (000) and (111) are complementarities states, all other states are referring to substitution effects (001, 101, etc.). Complementarity is represented by states where all drivers are present or absent at the same time. The economic significance of the hypothesis in a discrete world, is that the total effect of states where drivers are present/absent together is higher, on innovation outputs, than the effect stimulated by states where drivers are separately exerting their effects.

⁶ 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.

⁷ It is worth noting that the presence of a third driver doubles the relevant inequalities to test (from one to two), as shown. This requires a joint test of the two inequalities. Then, the same couples of tests are to be verified for couples 1-3 and 2-3. Overall, we have 6 inequalities to test compared to one in the simple 2-drivers case.

Summing up, following the results and the framework used in Mazzanti and Zoboli (2005, 2006)⁸, we here extend the empirical analysis focusing on the hypothesis of complementarity links. We select three main drivers of environmental innovation: environmental R&D, eco-auditing schemes, induced policy costs. All three potential innovative drivers emerged significant in Mazzanti and Zoboli (2005): we here aim at studying the extent to which their effects is associated to complementarity or substitution features. This is highly relevant for policy making issues, as it will be highlighted in the conclusions.

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.

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

3. 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 conducted on the same firms (2002 and 2004, eliciting data respectively concerning 1998-2001 and 2001-2004). 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 and Anton, 2002; Lee and Alm, 2004).

We ground 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 in year 2001. 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

⁸ We refer the reader to the paper for main hypotheses and applied results concerning the drivers of environmental innovations in industrial settings.

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 sources⁹. 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 here descriptively examine the extent to which innovation is influenced by size and sector, referring the reader to table 2 for a general overview on descriptive statistics concerning the main environmental factors investigated. 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 2b 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

⁹ The taxonomy of environmental realms is largely consistent with recent OECD studies (Darnall – Jolley – Ytterhus, 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 more specific data on innovations.

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%).

Environmental management systems are not widespread on average and in industrial districts as well¹⁰. Innovation intended as the adoption of (voluntary) auditing schemes (EMAS, ISO)¹¹ concerns 26% of firms. We can partially compare this outcome with that of Frondel - Horbach - Rennings (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 mainly present in the firms of the ceramic sector, which has experienced the achievement of a district-based EMS certification.

As a final analysis of this descriptive-oriented section, we briefly focus on potential complementarities among innovation drivers. As far as the latter is concerned, we follow Mohnen and Roller (2005) framework in order to check complementarities exploiting discrete data formulation for innovation drivers: we focus on auditing, R&D and induced costs. Some notes on complementarities are possibly drawn out from the observation of count statistics. For example, taking R&D and auditing (tab.3 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 of complementarities by systematic multi-variate analysis is presented in the core section below.

4. Theory and empirical models

4.1 Theoretical framework: main hypotheses

We focus on complementarities relationships concerning four main drivers of environmental innovation: (i) policy actions (induced policy costs); (ii) environmental R&D; (iii) eco-auditing schemes; (iv) networking activity. The primary aim is to verify whether the effect of such drivers on

¹⁰ 148 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.

¹¹ 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 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).

innovation is characterised by some sort of complementarity or policy induced costs (exogenous driver), R&D and auditing are substitutes in favouring innovations. We specifically want to test the complementarity between the voluntary auditing schemes with the policy-driven induced 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.

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). Those are dummies. Then, we exploit INNO-TOT (synthetic index of the adoption of the four environmental innovation, including reduction in the use of input materials).

We briefly comment the role of policy, auditing and R&D.

The role of policies in stimulating innovation is a long debated issue at both theoretical and empirical level (Grubb and Ulph, 2002). Given official policy-related data do not exist at micro-firm level, survey data is 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 induced 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). 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). Therefore, costs can also be accounted for as a part for the “achievements” of the policy (although with a possible negative sign) that parallel other achievements on the environmental side. What costs to include may

represent a final controversial point, which is to be investigated case by case. Financial costs, current and capital expenses, indirect costs, external costs, opportunity costs are all possible candidates to enter ex post evaluations. We elicited information on direct environmental costs linked to current expenses and 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.

Eco-Auditing schemes. 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. 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.

Although most of the literature emphasises the potential role of voluntary eco-auditing schemes as innovation drivers, the issue still remains debated. It has to be verified whether the voluntary market oriented auditing scheme is correlated with necessary R&D expenses, and with the effect of policy induced costs.

For example, Dosi and Moretto (2001) suggest that eco-labelling, which should enable firms to reap the consumer surplus linked to environmental attributes by identifying “green” products, may induce also perverse effects, such as increased investments in conventional technologies (more polluting with respect to new technologies) before the label is awarded. The effect stems from the existence of a complementarity relationship between polluting and green production lines, in addition to the award of labels for a subset of production lines, and not concerning all production activities.

Turning 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 a data concerning environmental R&D (for example, even Jaffe and palmer (1997) use R&D as driver of environmental innovation.

Finally, 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” (Glaeser - Laibson - Sacerdote, 2002): the positive relationship between R&D and social capital in an impure public good framework (Cornes - 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, by which achieving goals specific to the network but appropriable by participants, 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 (Cappello and Faggian, 2005). Finally, social capital/networking externalities might turn over standard Marshallian externalities in explaining growth and innovation processes¹². Network relations and high-performance oriented organizational strategies are indeed linked, since they may represent external and internal ways of innovating the organizational firm structure¹³.

We also control all specifications by entering firm structural variables. 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 use the number of firm employees as size proxy (including linear and squared terms). Additional control variables which may act as explanatory factors of innovation 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). 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, and may capture dimensional effects (GROUP).

¹² 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.

¹³ See Hansen - Sondergard - Meredith (2001).

4.2 Methodological issues in modelling innovation

Our empirical models set as dependant variables innovation proxies. 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 costs and auditing.

It is worth noting that in our case study, the share of firms reporting an environmental-related patent activity is very low (2%). This figure was 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 - 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 - Tang (2004), who stress that some firms protect property rights by trade secrets and copyrights instead of patenting.

Generally speaking, in any case, there is no shared theoretical 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. 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. 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”. We claim that when studying innovation output and input proxies from an applied perspective, a feasible and plausible way is to define reduced forms which attempt to explain innovation by exploiting a broad but theoretically consistent set of covariates¹⁴. This is a usual practice within the technological and organisational innovation oriented literature, which exploits the frame of a “knowledge production function”.

¹⁴ Hansen et al. (2001) present an analysis of case studies regarding environmental innovations in small and medium sized enterprises, for five European countries. 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).

(a) *Innovation output for specific innovations*

In order to perform this exercise, the estimation of an objective innovation function to develop tests for complementarity (super modularity), 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 it follows:

$$(1) \quad INN_{i,t} = \beta_0 + \beta_{1,t}(\text{structural firm features}) + \beta_{2,t/t-1}(\text{environmental policy proxies}) + \beta_{3,t}(\text{environmental R\&D}) + \beta_{4,t}(\text{environmental grants}) + \beta_{5,t}(\text{techno-organisational innovation}) + \beta_{6,t-1}(\text{industrial relations}) + \beta_{7,t-1}(\text{performances}) + e_i$$

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.

(b) *Synthetic index of Innovation output*

When estimating the total innovation index, ranging between 0 and 1, we face a limited but continuous variable. We deal with *fractional variables* (Papke and Woolridge, 1996), continuous but limited. It is possible to affirm 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, one limit or two-limits Tobit models are not a panacea, and often 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. Those two points (a) and (b) are relevant for the estimation of regressions for assessing environmental innovation drivers and when we test input complementarity using various innovation function specifications. 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 is holding between the two innovation outputs. In brief, the bivariate probit is employed when one wants to tests 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 complementarities relationships

This section presents the main results of the empirical case study. First, we set out the main hypotheses related to the impact of drivers on innovation. Then, after a short methodological discussion on innovation modelling and some empirical issues, we present results concerning main significant drivers of innovation and, consequently, the core examination of complementarity relationships for bivariate cases (couples of output innovations and input drivers of such innovations).

5.1 Examining the drivers of Environmental Innovation

We comment the following outcomes deriving first (i) from binary probit analysis, when disaggregating by “environmental innovation issues”¹⁵, and (ii) from estimations carried out on synthetic index of environmental innovation.

Before commenting results, given that data presents simultaneity for innovations, R&D, environmental costs and auditing schemes (all defined as trends over 2001-2003), potential endogeneity should be tested, though (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). 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.

Let us back to results. First, environmental innovation concerning emission-reduction shows to be positively influenced by the presence of voluntary auditing schemes. Concerning policy-related explanatory factors, we note that the (reported) presence of emission-related policy is positively related to innovation; nevertheless, quite interestingly, the probability of adopting emission innovations is inversely proportional to the number of years the firm has been subject to the policy. This number of years, reported by firms themselves, may depend on historical, productive and institutional reasons. The outcome is somewhat counterintuitive and will be confirmed below: following this evidence it seems that policy effects are stronger in the first phase of policy implementation, fading away with time. The explanation may be that we observe 2001-2003

¹⁵ See table 4a for a summary of main outcomes of such analyses and tab 4b for a description of variables used.

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, as well as environmental costs¹⁶ and investments). Size and sector controls do not influence adoption. The index of “participative innovation oriented” industrial relations is a positive driver. Finally, firm performances do not matter.

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

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

Finally, we examine the 0-1 continuous index capturing all realms of innovation (INNO-TOT). OLS corrected estimates show (tab.4a, last columns) that (i) R&D and costs are significant while investments are not (regression 4); (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). 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

¹⁶ Predicted values of costs are included following the endogeneity test, but they do not arise significant.

decisional processes on high-performance and organisational strategies. Performances confirm not to influence environmental innovation¹⁷.

Summing up the results, we first note that size effects are not significant. Market features also do not matter. By sector, effects on innovation are not strong but more evident: the chemical and ceramic sector emerges as moderately important drivers in some cases.

Other firm characteristics instead influence the adoption of innovation more evidently: organisational flatness is generally emerging a driver of innovative output, and the variables concerning industrial relations, mainly the synthetic index IND-REL, exerts overall a positive influence on the adoption of innovations.

Concerning policy drivers, direct and indirectly conceived, we find that Policy-related proxies are relevant for emission and waste policies, with a somewhat counterintuitive negative effect in relation to the “number of policy years” effect. Environmental induced costs (current expenses and policy related expenses) instead arise as a core driver for most innovative output specifications.

Turning to R&D, we observe that it arises as a primary driver for most innovation output realms. Within the realm of “organisational innovations”, a clear positive association is shown to exist between all output innovations and voluntary auditing schemes.

Grounding on these results, we now move to what in our opinion is the value added analysis of the paper, focused on examining the extent to which innovation output and, above all, R&D, eco-auditing, networking and induced policy costs are complementary within the innovation system of the firm. The selection of the set of drivers depends both on theoretical considerations and on the above commented evidence, which shows their relevancy in our case study.

5.2 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). 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. On this basis, let us analyse what is instead the degree of complementarity between the drivers of such innovation outputs.

¹⁷ Count data models do not provide a striking different evidence.

5.3 Input complementarities: R&D, auditing and costs

This section presents applied results for complementarity tests. We first show outcomes of bivariate tests, using *couples of drivers (bivariate case)*, then we focus attention on joint test for complementarities concerning the *full vector* of three drivers/inputs (*joint case*). We recall that the discretely defined drivers (dummies) generate a set of potential combinations, technically 2^n ($n=2$ for the bivariate case and $n=3$ for the joint case). When focusing on bivariate cases, the framework collapses to a single sufficient hypothesis on complementarity. When reasoning around complementarities for a vector of more than two drivers, statistical analysis enters the realm of joint inequality tests (Kodde and Palm, 1986; Mohnen and Roller, 2005). It is necessary to test a set of joint hypotheses, deriving from the (increased) potential combinations (states). As said, in our case the three dichotomous drivers generate a set of eight potential driver combinations, technically 2^n ($n=3$ in our case), and three sets of two (joint) hypotheses. The three sets are associated to the three couples (1-2, 1-3, 2-3); the two within-sets hypotheses are necessary given that for each case two states exist (0, 1) with respect to the other (third) driver.

We also recall that the innovation function is super modular over a (chosen) subset of its arguments, if and only if all pair wise elements are satisfying the complementarity definition (see below). This means that with more than two elements, on the one hand it is sufficient to check all pair wise complementarities characterising the selected drivers: but only if all turn out to hold, the innovation function is super modular in those explanatory arguments.

Regarding the object 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: size, sectors, international and subcontracting market shares, group membership. In order to further test the robustness of results, by including additional covariates, which resulted significant from regression analysis (par. 4.3), in order to verify the sensitivity of results to potential omitted elements. We note that in order to estimate the regression it is necessary that all states are represented in the sample (by at least one agent). In fact, it is necessary to estimate all parameters to carry out the test on the hypothesis of complementarity.

Table 3 presents the states of the world regarding the potential combinations of the drivers; last row shows the ranking in terms of occurrence.

In order to carry out bivariate tests on innovation input complementarities¹⁸, we first specify regressions entering the four dummies associated to the potential states of the world for each bivariate case: 00, 01, 10, 11, where one, as said, means presence and zero absence of the driver in a

¹⁸ Tests of complementarity taking jointly R&D, auditing and induced costs are scope for further research. We recall that the assessment of super modularity of the innovation function requires the test for complementarity by pair wise comparisons. Thus, when we face three pair wise situations only if all three turn out to confirm the complementarity link, then the function is super modular in the sub set of the three arguments. Statistically, this analysis requires a joint test of inequality restrictions concerning the three pair wise driver combinations, using Wald test routines as developed by Kodde and Palm (1986).

specific firm. All coefficients related to state dummies have to be estimated; the model is thus a without constant specification (dummies statistically enter as constants), instrumental to estimate the parameters for carrying out the test. We recall that in a bivariate framework we need to test a single hypothesis of the form $[b_1+b_2-b_3-b_4 \geq 0]$, where b_1 and b_2 are the estimated parameter linked to “complementarities states” (i.e. (00), (11)), while b_3 and b_4 are associated to “substitution states” ((10), (01)). A one sided t test is sufficient when the reasoning collapses to a single hypothesis, when $n=2$. 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 concerning each specific couple, case by case.

Estimates and consequential test analysis show that the complementarity hypothesis holds in most cases¹⁹ (tab.5.2). We nevertheless note that (i) the cost-related variable is particularly associated with negative signs of the test; (ii) only in one case (R&D-Costs for the emission-related innovation specification) the t value leads neatly to a rejection of the null. R&D and induced costs seem to be substitutes drivers in this specific context. We also observe that, although the null is specified as ≥ 0 ²⁰, the only case where complementarities would hold even in a strict sense (>0) is that for auditing - R&D in the adoption of energy related innovations. Taking the overall picture, we may observe that complementarity, defined as above, holds for most specifications but one. The cases with induced costs register a higher occurrence of negative signs, though only in one situation this leads to a rejection of the null.

Entering additional explanatory elements (firm hierarchical intensity, industrial relation index, other techno-organisational innovations, etc..) do not change the picture with respect to complementarity tests. Results are thus note sensitive to the inclusion of additional covariates, though some (see also above) are statistically significant and improve the fit of the regression with respect to the base specifications with states and controls only. We note that the significance of those explanatory variables is unaltered moving from a specification without constant and fours states to a model with a constant, omitting one state.

The statistical and economic connotation of state dummies change when a constant is included (and one state is omitted) in order to specify a usual regression model. Although it does not exist a shared view around the interpretation of such state dummies when they are (all) estimated in the “instrumental regression”, it is clear that they posses an economic meaning when estimated as usual

¹⁹ Although the signs of t statistics associated to some regressions may be both negative and positive, depending on the dependant variable and on the tested bivariate relationship. In any case, overall, the null hypothesis of complementarity cannot be rejected.

²⁰ 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 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.

dummies, capturing various effects on innovation. We observe that states (11) and (00) are always respectively associated to positive and negative signs of coefficients, and are also statistically *generally* significant. This is proved for cases concerning R&D/auditing and costs/auditing. Concerning (01) and (10) state dummies, we may observe that auditing effects seem to be more significant, as driving force, than the R&D effect.

5.4 R&D and networking

A separate comment deserves the link between R&D and networking (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. For example, Cainelli et al. (2005, 2006) 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 show 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 complementary evolve only if the opportunity cost of investing in innovation is sufficiently low. When empirical evidence confirms that this complementarity plays key role, the policy effort should be targeted toward both market and non-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. Recent works are also Fritsch e Franke (2004) e 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.

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 induced policy costs and auditing are included as covariates, otherwise when only controls are included substitution emerges. Thus, the outcome is not robust to the vector of independent variables. As far as emission innovation is concerned, complementarity holds, but not on a strict basis. The null hypothesis is the complementarity state under a non strict inequality (≥ 0)²¹; we thus test complementarity in a non strict framework. Only if

²¹ 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 ($b_1+b_2-b_3-b_4 > 0$), while a negative value

a negative value is observed below the defined threshold (e.g. 5%, 1%) we may conclude and reject the null at the specified significance level. Concerning waste, the same outcome observed with the synthetic index of innovation emerges, while regarding energy innovation complementarity also holds on a non strict basis. The evidence is thus mixed: in two cases out of four complementarity holds in a non strict basis, independently on the included covariates; in the other two cases, strict complementarity or substitution emerge depending on which covariates are included. Though complementarity signals may be greater than substitution signals, we cannot conclude that the hypothesis of complementarity is robustly emerging from our data²².

To conclude this section we observe that although our analysis shows and probably confirms an (expected) hypothesis of correlation/complementarity between drivers, this generally emerges in a non strict way. We also find cases where such main drivers, induced costs, R&D, networking and auditing, 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 paper scope is twofold. First, it provides new empirical evidence on the drivers of environmental-linked innovation at a microeconomic level. Following this empirical evidence, we consequently test complementarity relationships characterising main innovation drivers of innovative output and innovation output correlations as well. We exploit a recent and rich survey based datasets covering many potential innovation-related factors. 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.

Summing up on 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 management-employees relationships along more flexible and innovative scenarios, and policy-related elements such induced costs all may bring about environmental innovations, impacting firm strategies and firm behaviour.

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.

²² We cannot test complementarity with respect to specific dynamics of networking (i.e. university, clients, competitors) since our sample size does not allow a significant statistical segmentation into different networking typologies.

As far as the analysis of complementarity is concerned, our results show that the null hypothesis of complementarity generally holds, though on a “non strict” basis²³. Nevertheless, we observe that the complementarity link, though predominant across the various analysed couples of drivers, is rejected in some case (tab.5): while it is always valid for the total synthetic index of environmental innovations (intensity of innovation), this is not true for binary indexes of specific innovation adoption. The null is rejected at a significant 5% level when analysing R&D and policy costs regarding emission related innovations. Moreover, if one the one hand waste innovations are characterised in all three cases by complementarity, this is not true for energy related innovations, where the t ratio for the test on auditing and R&D shows a significant 5% rejection of the null. Concerning R&D and networking, the picture, though more biased towards complementarity, cannot lead to a robust assessment of the hypothesis.

Thus, although our analysis shows and probably confirms an (expected) hypothesis of correlation/complementarity between drivers, we also find cases where such main drivers, induced costs, R&D, networking and auditing, are not complementary.

Instead, as far as innovation outputs are concerned, the correlation analysis show that firm 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. All in all, output innovations seem to be adopted jointly, with a strong complementary dynamics, while on the input side we may conclude that for the generation of innovations, drivers complementarity is relevant, though the evidence does not allow us to consider and suggest the complementarity element as a primary factor in explaining innovation. Effects on innovation may be associated primarily to single factors influence: investments in R&D, induced policy costs, auditing schemes, with networking playing a relevant, but probably indirect, role. Complementarity is then supporting innovative dynamics, but as a secondary force, at least as far as our data are concerned. We remark that the literature on innovation, performance and complementarity at firm level has shown the high level of contingency for the validity of the complementarity hypothesis. The validation of the hypothesis, on a strict or non strict sense, depend 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.

Policy implications may be the following. On the one hand, empirical evidence shows that, *though 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

²³ Non strict complementarity may be associated to a sort of constant returns to scale, while strict complementarity directly point to an effective situation of increasing returns concerning the analysed factors.

R&D and (associated) cooperative networks, and to increase the costs of managing environmental resources to induce innovation adoptions. The extended multivariate analysis also shows the joint importance of exogenous and endogenous firm-related drives in complex industrial settings, where policy actions and the territorial involvement of social parties (unions) are both relevant to explain and favour environmental dynamics.

Drivers shows to be associated to each other by some elements of complementarity, though mild. Though the causality direction is not easily assessable, firm investments in environmental R&D, regulatory related costs and the adoption of auditing voluntary schemes like EMS and ISO seem to evolve complementary for most innovation typologies. When complementarity does not hold, the policy effort must consider a dis-joint action (two different instruments) on the set of potential targets (e.g. R&D and auditing), while complementarity allows economies of scale in pursuing objectives, given increasing returns in stimulating innovations. One tool is probably needed; in any case, complementarity assures increasing returns associated to innovation dynamics in firms.

To sum up, our analysis suggest 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. Thus, though the number of tools may somehow be efficiently lower than the number of policy objectives (i.e. R&D, networking, environmental costs) it remains also scope and space for stimulating different innovation drivers by using different tools. Concerning firm management, complementarity of technological and organisational elements helps firms to reap some increasing returns, though this is highly dependant on the type of environmental innovation and on the couples of drivers we focus on. Complementarity is 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						Total (%)	Total (Absolute value)
	50-99	100-249	250-499	500-999	> 999			
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					Total (%)	Total (Absolute value)
	50-99	100-249	250-499	500-999	> 999		
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- 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. 3- 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 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. 4a- Econometric regressions (output innovation)

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

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

Tab. 4b. Description of main covariates and acronyms used in regression

Acronym	Variable description
Log-Size	Logarithm of firm size (employees)
CHEM, MACH, CERAM	Dummy variables: value 1 if belonging to chemical, machinery, ceramic sector
GROUP	Dummy: value 1 if belonging to industrial groups
HYER	Index of firm hierarchical levels on firm functions (hierarchy ratio)
IND_REL	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. 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.
POL-WA/EM	Dummy; value 1 if the firm has been subjected to policy (waste / emissions)
POL- WA/EM (YRS)	(log) number of years since the policy was introduced
Grant	Dummy, value 1 if a firm has exploited a public grant for innovation purposes
ENV-INV	Investments in environmentally oriented capital equipments, per employee
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
R&D	Environmentally oriented R&D expenses per employee
R&D dummy	Dummy variable: value 1 if environmental R&D >0
AUDIT	Dummy variable: value 1 if auditing schemes adopted
EMAS, ISO ₁₄₀₀₀	Dummy variable: value 1 if specific EMAS or ISO schemes adopted
PROD ₉₈₀₀	Firm productivity average level 1998-2001 (from balance sheets)

Tab.5.1- Bivariate probit analyses (correlation values)

<i>Dependant variables</i>	<i>Correlation (T value)</i>
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 ²⁴
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	0.1/1.10

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

²⁴ 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 to 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.

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	Automotive 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.