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The drivers and implications of environmental innovations:

European evidence at different levels of analysis

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Introduction: rationale and synopsis of the thesis

The ten-year growth strategy "Europe 2020" set for European countries the policy objective of achieving a "smarter, greener and more inclusive economy" by the year 2020. This policy has been articulated into five objectives, which combine employment, innovation, environmental, education and social inclusion goals in a broad and comprehensive strategy.

In this broad policy framework, a more sustainable economic growth is deemed to depend upon improvements towards a greener production that may lead to a "decoupling" between environmental pressure and economic growth and allow to achieve the greenhouse gas emissions reduction target without giving up to economic growth.

These improvements towards greener production techniques depend upon the firms' adoption or generation of environmental innovations (from now on EI). EI are crucial to improve the sustainability of the production processes, either when innovations are integrated in the production process (in the literature defined as "Cleaner Production" measures), or when innovations are add-on measures which allow to reduce the negative externalities of the production in the last stage of the production process, for example by including specific filters to reduce pollution (in the literature this typology is defined as "End of Pipe technologies").

As it will emerge in this work, EI show some peculiarities with respect to standard technological innovations that motivate their investigation, either in the drivers and in the effects. Looking at their effects, not only EI allow to move towards a more sustainable production of goods and services, but can also be central for generating new growth and job opportunities, as the new products or production processes can have the side-effect of boosting productivity, growth and reducing production's costs (Montresor et al., 2013). Consequently, their potential for policies aimed at reaching a smart and more sustainable Europe is big. Moreover, EI are considered a special typologies of innovations (Rennings, 1998; 2000), whose investigation brought to the rise of a strand of literature specifically aimed at understanding their nature and drivers. As it will emerge in the following section and in the first Chapter, EI are indeed influenced by a more systemic interplay of the traditional drivers that have been identified for standard technological innovations and the knowledge required to their adoption goes beyond their existing industrial knowledge base, thus requiring the need to explore new knowledge sources.

Furthermore an important distinction has to be made between (green) invention and EI, mostly because for EI to play their joint economic and environmental effect, those have to be actually adopted by firms. Their invention, when it is not translated into an adoption, is indeed not enough to allow them to play their potential. This consideration has important implications also on the appropriate choice of the indicators and variables that are selected to properly frame an empirical investigation on the topic. A discussion of this choice will be provided in the following Chapters.

Before starting a proper analysis on this research field, given the complexity of the framework of analysis that has been anticipated so far, it is useful to first make clear what exactly we are going to talk about, i.e. how EI are defined and how they can be measured. After having provided the reader with the main definitions which are at stake, the structure of the thesis will be presented.

Definitions of environmental innovations

Starting from James' definition of EI as "new products or processes which provide customer and business value but significantly decrease environmental impacts" (James, 1997:53), many attempts have been made to enrich such a definition in order to account for the complexity and specialty of EI (Rennings, 1998; 2000) that will be soon described.

One of the broadest and more comprehensive one came from the "Measuring Eco Innovation" (MEI) project, which defines EI as "the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organization (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives" (Kemp and Pearson, 2007:7).

This definition is inclusive of all those EI which are not necessarily *new to the world* but are at least *new to the organization* adopting them, as the Oslo Manual on innovation suggests to (OECD, 2005).

Moreover this definition allows to consider as an EI not only new environmental technologies, but also any new/improved product or process or service (Kemp and Pearson, 2007). From this it follows that "all new processes that are more eco-efficient are eco-innovations" and that "the term eco-innovation crucially depends on an overall assessment of environmental effects and risks" (Kemp and Pearson, 2007: 7).

A feature of this definition that needs to be underlined is the focus on the environmental performance of innovation itself, rather than on the mere environmental aim. This suggests how in the definition the effective achievement of environmental improvements after the adoption of an innovation is more important than the motivations underlying it.

Accordingly, an "unintended" EI that has environmental effects should be considered as an innovation towards sustainability, while the intention of a firm to introduce an EI should not be accounted for until it is adopted.

Like in the case of standard technological innovations, several measures are available to measure EI empirically. Although the differences between EI and standard technological innovations (that are described in the next section), the indicators proposed by Kemp (2010) to measure EI are nothing new with respect to those already available for the measurement of standard technological innovations, with the exception of the last one. Those are the following:

1. Input measures: Research and development (R&D) expenditures, R&D personnel, or innovation expenditures;

2. Intermediate output measures: i.e. those indicator that do not measure directly the output "innovation" but can approximate it for instance through the number of patents or scientific publications;

3. Direct output measures: the number of innovations, descriptions of individual innovations, data on sales of new products;

4. Indirect impact measures derived from aggregate data: i.e. those indicators that indirectly measure the impacts of the adoption of EI extrapolating them from aggregate data. An example of such an extrapolation is the measurement of changes in resource efficiency or in productivity measures that can be applied through decomposition analysis techniques.

According to Kemp (2010), the most used indicator for measuring empirically EI is the number of patent, mainly because it is a widespread indicator, easy to be collected, and allows for international comparisons.

Using patents as a proxy for innovation have some drawbacks that require to be accounted for. The main one is that patents measure inventions rather than innovations. In other words, patents provide an indication of new knowledge that is generated, but it cannot be taken for granted that these inventions will enter the market. Moreover, not all the patents have a commercial value and strong sectoral, country and temporal heterogeneities emerge when one looks at the propensity to patent. Lastly, only technological invention can be patented, thus excluding organizational and marketing innovation. A broader discussion on the limits of using patents to approximate innovations is provided into Chapter 2.

Given on the one side the availability of data and on the other side the drawbacks that the choice of one indicator instead of its alternatives entails, in the current work two alternative but at the same time complementary measures to capture EI are going to be exploited.

In the first and the third Chapter, a direct output measure of the adoption of EI will be used. In these Chapters EI are defined, similarly to the definition provided above, as "a new or significantly improved product (good or service), process, organizational method or marketing method that creates environmental benefits compared to alternatives" (Community Innovation Survey 2006-2008: Section 10). Furthermore, "the environmental benefits can be the primary objective of the innovation or the result of other innovation objectives" or "can occur during the production of a good or service, or during the after sales use of a good or service by the end user" (Community Innovation Survey 2006-2008: Section 10).

Data on EI come from two different but interrelated survey sources, the COMMUNITY INNOVATION SURVEY 2006-2008 provided by EUROSTAT, exploited into the first Chapter and the MANNHEIM INNOVATION PANEL 2009 and 2011 provided by the Center for European Economic Research-ZEW, exploited into the last Chapter.

In the second Chapter an intermediate output measure will be instead used to proxy EI. In particular a patent-based analysis has been implemented and, according to a methodology that will be discussed in the Chapter, an assignment to each patent to the "Environmental Realm" has been conducted according to the technology field of each patent.

What spurs the adoption of environmental innovations?

A necessary step for any analysis dealing with EI is to understand their determinants, i.e. those elements which spur their adoption or generation by firms. This is a crucial element as it can help policymakers and managers to properly promote the adoption and diffusion of EI.

On the one side the "standard" innovation studies literature has outlined a set of determinants that affect firms' adoption of technological innovations. Although the understanding of what drives innovations is still a debated issue, a general framework can be drawn. Innovations could mainly be "science-pushed" or "technology-pushed" , i.e. can be driven by advancements in science and by R&D, they can be "demand-pulled", i.e. can be driven by market conditions, they could be "regulatory pushed", i.e. driven by policies that for instance might set new standards, or also by a combination of the previous elements (Carter and Williams, 1959; Kleinknecht and Verspagen, 1990; Schmookler, 1966; Walsh, 1984).

On the other side, the relationship between EI and technological innovations is not straightforward, since, from the seminal contribution by Rennings (1998), the literature stressed that EI are "special" innovations for at least three reasons. The main one is the "double externality problem", determined by the the nature of EI as innovations that on the one side act to reduce negative environmental externalities and, on the other one, are themselves subject to externalities, which are driven by knowledge spillovers, that could potentially lead to sub-optimal investments towards their adoption. Furthermore EI are characterized by the "regulatory push/pull effect", as they are strongly regulation driven and regulation might act both on the supply (push) and on the demand side (pull). Lastly EI are strongly depending on social and institutional innovations, as many issues in the sustainable use of resources and in the reduction of negative environmental externalities are not primarily technological (Rennings, 1998).

As a consequence of these "specialties", an ad hoc literature on the specific determinants of EI has emerged, which is connecting the above mentioned "standard" studies on innovations' determinants and the new research efforts in the realm of EI determinants. As we will see, results in their determinants are not fully comparable, suggesting that the choice of treating EI as "special" innovations is appropriate.

My original contribution to this literature on the determinants of EI is given mainly by the first Chapter of this thesis. In Chapter 1 the focus is on the role of external knowledge sourcing strategies in facilitating, among the other determinants, the adoption of EI by firms. This analysis will be implemented on survey data from the Community Innovation Survey 2006-2008 for manufacturing firms in eleven European countries.

What induces climate change technologies and which is the role for regulation?

What emerges from the literature on EI is that they are usually more regulation driven than "standard" technological innovations (e.g. Rennings, 1998), as in the absence of a policy aimed at fostering EI, through for instance the imposition of environmental standards to be reached, these innovations are less likely to be adopted than standard technological innovations. An exception to this evidence comes for EI aimed at reducing not only the environmental impacts but also the costs of production. Innovations leading to a reduction in the use of energy or materials per unit of output have indeed appeared to be less regulation driven than other EI (Rennings and Rammer, 2009).

A wide strand of literature has emerged trying to understand the relationship between regulation and the generation of greener technologies, or the adoption of EI.

These studies are either based on patent data (e.g. Brunnermeier and Cohen, 2003), or on survey data (e.g. Rennings and Rexhäuser, 2011). Empirical evidence of a positive correlation between EI and regulatory stringency has been depicted, pointing to the conclusion that regulation is a key driver of EI.

It is also clear from previous literature that innovation in climate change might be induced by strict and properly designed environmental regulation.

However, countries differ in the enforcement and characteristics of environmental regulation, so that in some cases a weaker regulatory framework is depicted.

In such cases it might worth analyzing which mechanisms facilitate the adoption or generation of EI.

This is the scope and at the same time the originality of Chapter 2, in which a regional and sectoral analysis on patent data in "Environmentally Sound" technology field on Italian Regions will be performed.

Which are the economic implications of environmental innovations?

Very debated is the so called "Porter hypothesis" (Porter and Van Der Linde, 1995), according to which environmental regulation is not necessarily a cost burden for the firm, but, when properly designed and flexible, might engender positive effects on firms performances, as it can signal opportunities that firms might not be aware of. There is no universally accepted position regarding this hypothesis, and the literature tried to test it in heterogeneous ways by decomposing it into a strong, a weak and a narrow version (for a review see Ambec et al., 2013).

Understanding the economic implications that the adoption of EI has on firm's competitiveness is in this last respect an interesting contribute to the debate. This is the objective of the last Chapter, in which an analysis on the effects of the adoption of EI on firms' competitiveness will be performed on the "Mannheim Innovation Panel" dataset. As it will emerge in the Chapter, economic competitiveness is a broad concept that encompasses shorter and longer term implications. These include, for instance, effects on profitability, employment effects, productivity gains and increases or losses in exports or Foreign Direct Investments (FDI). The analysis performed in the Chapter is meant to understand whether the adoption of EI engenders gains or, on the contrary, losses not for the whole economy rather for the firms adopting EI. Consequently a short term measure of competitiveness centered on firms has been exploited and the indicator chosen provides a measure of firms' profitability.

EI will be disentangled into multiple categories of innovations: such as those innovations leading to a reduction in the use of materials or energy per output and those reducing production externalities such as harmful materials and air, water, noise and soil pollutions. This differentiation is coherent with the findings and suggestions of previous literature in the field (Rennings and Rammer, 2009; Rexhäuser and Rammer, 2013).

The competitive gains or losses of different typologies of EI are going to be tested for these two categories. Energy and resource efficient innovations may lead to "win win" situations, in which reducing the environmental impact of production is contextually improving firms' economic performances. The same expectation does not hold for externality reducing innovations, for which the cost burden of the adoption of the innovation might overcome the potential gains.

Furthermore we test whether the motivation behind firm's decision to engage in an environmental-innovative activity can moderate the competitive gains of EI adoption.

The originality of this essay lies in the decision to disentangle the profitability effects of an innovation by typology of EI and by the motivation that drove firms' decision to adopt EI.

Structure of the thesis

The present work is a collection of three essays that shed light on EI adopting different but strictly related schumpeterian perspectives. Each of the essays is an empirical analysis that will investigate one of the broad research questions outlined in the previous section and will be presented into separate Chapters from Chapter 1 to Chapter 3.

The first Chapter is devoted to understand the determinants of EI by focusing on external knowledge sources; the second Chapter answers the question on what induces climate change technologies adopting regional and sectoral lens while Chapter 3 analyzes the economic implications of the adoption of EI for firms.

Each Chapter draws on a different dataset. The exploitation of several data sources is an element of richness of the thesis, as it allows a better extension of the results that emerged and it is also a way to overcome the limits that the choice of one dataset with respect to its alternatives engenders.

Microdata (i.e. firm level data) from the Community Innovation Survey 2006-2008 for eleven European countries is exploited in the first Chapter.

The empirical analysis of the second Chapter is based on patent applications at the European Patent Office (EPO) extracted by PATSTAT and REGPAT, on firm level data available in ORBIS, a Bureau van Dijk data-source and on a set of economic and environmental indicators published by the Italian statistical Office (ISTAT): mainly the regional Accounting Matrix including Environmental Accounts (Regional NAMEA), Input Output Tables and Economic accounts.

Chapter 3 is instead centered on the exploitation of two waves of the Mannheim innovation Panel, the 2011 and the 2009 one.

The three essays differ not only in the research hypothesis and in the dataset used to their tests, but also on the methodology. Given the structure of the dataset and the nature of the dependent variables, the first Chapter performs *logistic* regressions, the second one performs *zero inflated negative binomial* regressions and a *principal component analysis*, while the last one performs *interval* regressions techniques. Together with the choice of multiple datasets, the heterogeneity in the methodologies applied certainly enriches the current research thesis.

A general conclusive Chapter will follow the three essays and will outline a set of policy implications that have been derived from the whole thesis.

Chapter 1

The interactive drivers of environmental innovations. European evidence on eleven countries

Claudia Ghisetti

Abstract

The aim of the paper is to investigate the impact that knowledge sources external to the firm have on its environmental innovations. Using the CIS 2006-2008, it is estimated the impact that sourcing strategies of external knowledge have on the probability of introducing environmental innovations by the firms of eleven European countries. Both the depth and the breadth of knowledge sourcing impact positively on environmental innovations, signaling their positive role among the determinants of environmental innovations. Interesting non linearities are however depicted: knowledge heterogeneity entailed by the breadth knowledge sourcing could become an obstacle to firm's environmental innovativeness, after a certain threshold, as it is the case for technological innovations.

JEL codes: Q55; O31; O32.

Keywords: Environmental innovations, Open innovation

1.1 Introduction

Environmental innovations (EI) are nowadays key policy targets, in the perspective of achieving a "decoupling" between environmental pressure and economic growth and to foster a "smarter, greener and more inclusive economy" ("Europe 2020 Strategy"). The importance of EI has stimulated an intensive research effort, which has rapidly highlighted their manifold nature.

EI are, at the same time, technological, organizational, social, and institutional innovations (Horbach, 2008). Their study thus needs to go beyond the focus that environmental studies initially reserved to policies and regulations issues (Kemp, 2010).

The analysis of EI has actually become truly multidisciplinary. In particular, it has benefited from a cross-fertilization of ideas between disciplines which share a "system" kind of approach to innovation. The bridging between ecological economics and innovation studies, for example, has revealed extremely fruitful to address those "special" elements which characterize EI: the so-called "double-externality problem", the "regulatory push/pull effect" [1] and the need to take into consideration the ecological, social and institutional co-evolving context (Rennings, 1998).

The extension of systemic approaches to the realm of EI, has stressed the role that both external knowledge sources and cooperation have in spurring the adoption of EI. More precisely, an important general result has been extended to the EI realm: external knowledge sources and cooperation are at least as important as those within the firm (e.g. R&D). Although with a number of specifications - for example, about the kind (e.g. private business vs. public research) of external source - this result supports the system approach to the analysis of EI. On the one hand, the literature on the so-called "open innovation" mode is proliferating (Chesbrough, 2003, 2006) and offering interesting insights about the role of external knowledge for "standard" technological innovations (Laursen and Salter, 2006; Henkel, 2006).

On the other one, little attempt has been done so far to extend such literature also to include environmental innovations.

The remainder of the paper is organized as it follows. In section 1.2 the relevant literature is provided, together with the research questions. Section 1.3 presents the empirical strategy, in Section 1.4 results are outlined and Section 1.5 concludes.

[1] Regulation may indeed act both on the supply and on the demand side (Cleff and Rennings, 1999; Rennings and Rammer, 2009).

1.2 Literature Review

After an intense definitory effort (e.g. Kemp and Pearson 2007; Kemp, 2010; Rennings, 2000), a consensus has emerged on the notion of EI as: *"the production, assimilation or exploitation of a product, production process, service or management or business methods that is novel to the firm [or organization] and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives"* (Kemp and Pontoglio, 2007, p. 10).

The literature on EI determinants acknowledges they are stimulated both by "market-pull" and by "technology-push" factors, coherently with the evidences outlined for technological innovations (Pavitt, 1984). Beyond them, a regulatory push/pull effect is a key driver for EI (Cleff and Rennings, 1999), mainly due to the public good nature of EI. This *regulatory push/pull* effect, together with the *double externality problem* and their need for a co-evolution with the ecological, social and institutional setting, give EI a "special" connotation (Rennings, 1998).

This "specialty" is the reason why a specific strand of literature has emerged, aiming at outlining their determinants.

Extant literature has mainly focused on four clusters of determinants: "Market-pull", "Technology-push", "Firm specific factors" and "Regulation" (Horbach et al., 2012).

As for the first, turnover expectations, new demand for eco-products (Rehfeld et al., 2007), past economic performances (Horbach, 2008) and customer benefits (Kammarer, 2009) have been mainly assessed.

As far as the "Technology-push" determinants are concerned, firms' technological and organizational capabilities have been investigated, such as their engagement in R&D, knowledge capital endowment (Horbach, 2008), organizational innovations and specific management schemes like EMS (Rehfeld et al., 2007; Wagner, 2008; Rennings et al., 2006; Ziegler and Nogareda, 2009; Ziegler and Rennings, 2004).

"Firm Specific factors" such as firms' size, location, sector and age are also co-affecting firms' environmental innovativeness, and have been accounted for by the majority of the previous investigations (e.g. Mazzanti and Zoboli, 2009; Horbach, 2008; Rehfeld et al., 2007; Wagner, 2008; Rennings et al., 2006; Ziegler and Rennings, 2004).

Lastly, "Regulation" has been recognized as key determinant for EI in several empirical studies (Del Rio Gonzales, 2009) based either on survey data (e.g. Frondel et al, 2008; Hemmelskamp, 1999; Horbach et al., 2012, Rennings and Rammer, 2010; Rennings and Rexhäuser, 2010) or on patent data (e.g. Brunnermeier and Cohen 2003; Costantini and

Mazzanti, 2013 in press; Jaffe and Palmer, 1997; Johnstone et al., 2010, 2012; Lanjouw and Mody, 1996, Popp, 2006). A number of elements - e.g. strictness, enforcement, predictability, sectoral differences, credibility of the commitment to standards, and combination with other policies - have however made this regulatory push difficult to be measured and estimated (Kemp and Pontoglio, 2010).

Relatively less attention has been instead paid, up to now, to the EI drivers of interactive nature, such as those processes depicted for technological innovations of knowledge-exchange and sharing, knowledge sourcing and transfer, and innovation cooperation which involve innovative firms along with other actors of their innovation systems (Arora and Gambardella, 1994; Veugelers, 1997; Tödling and Kaufmann, 2009). In a nutshell, for their technological innovations, firms benefit extensively from learning-by-interacting with external actors, which provide them with additional knowledge and intangible assets (e.g. human capital) to be complemented with the internal ones.

As they are not easily contracted through market-based transactions (Sinha and Cusumano, 1991), by cooperating with other firms and/or research organizations (e.g. through R&D partnerships), innovators can more easily tap into the competence and experience of the external providers. Furthermore, they can share the risks and costs of their R&D projects and try to benefit from economies of scale (Hagedoorn, 1993; Tether, 2002)[2]. In contrast to this richness of results, the analysis of the interactive drivers of EI is still quite scanty.

Among the few recent contributions, it has been found that innovative oriented industrial linkages and inter-firm networking could trigger EI in a similar way to other innovations: for example, by providing firms (SMEs, in particular) with a way to compensate for their lack of economies of scale (Mazzanti and Zoboli, 2009). On the other hand, innovation cooperation (e.g. in R&D) has been shown to work more effectively for EI than for non-EI (De Marchi, 2012), but also more selectively. For example, business suppliers (Horbach et al., 2012) and universities (Cainelli et al., 2012) appear to be the only partners for which it has a significant impact. Furthermore, information from partners which are external to the supply chain (e.g. KIBS, research institutions, Universities and competitors) result more important for EI than for other innovations (De Marchi and Grandinetti, 2013).

[2]These and other results have been refined and extended by regional and economic geography studies. In particular, the innovation outcome of the interaction/cooperation has been shown to depend on the diversity between the objectives and incentives of the partners (e.g. Mora-Valentin et al., 2004; Belderbos et al., 2004; Arranz and Fdez de Arroyabe, 2008) and of the manifold proximity which separate them (Boschma, 2005).

The systemic nature of EI has appeared to require information and skills which are distant from the traditional industrial knowledge base (De Marchi, 2012). Similarly, agglomeration economies impact positively on EI only in those industrial districts in which the subsidiaries of multinational corporations inject global environmental pressures at the local level (Cainelli et al., 2012).

All in all, evidence begins to emerge that eco-innovators could also benefit from an "open innovation mode" (Chesbrough, 2003, 2006), in which the knowledge boundaries between the innovative firm and the environment become permeable, the outcome of its internal research effort gets combined with that of other companies and/or research organizations (e.g. through licensing, joint ventures, and cooperation), and the risks and the rewards of the resulting innovations are shared. As a further step forward towards the substantiation of this hypothesis, it is interesting to investigate whether some other pillars of the open innovation mode are at work also with respect to EI, and eventually with which characterisations.

At the core of "Open Innovation" mode (OIM) external information sourcing is an EI driver of interactive nature which is currently under-investigated by the EI literature. Contrarily, a rich strand of literature on technological innovations has investigated the potential of external knowledge strategies, showing that investing in broader and deeper search can increase firm's ability to adapt, change, innovate and boost business performance (e.g Chesbrough, 2003, 2006; Laursen and Salter, 2006).

Following Laursen and Salter (2006), it can be argued that, also with respect to EI, two characteristics could affect its outcome. The first one is the *breadth* of the firms' knowledge search, accounted by number of sources they search for in order to innovate. The manifold nature of an EI, and the different capabilities which it requires (e.g. technological, organization and institutional), makes the eco-innovator possibly more reliant than the standard one on numerous, external knowledge sources: the number of sources the firm search for is expected to be a significant predictor of its capacity to deal with its systemic nature and thus to actually eco-innovate.

The second feature of the knowledge search strategy which deserves consideration for EI is its *depth*, meant as the extent to which firms draw deeply from their external sources. The complexity entailed by EI, and the diversity of the knowledge base that it requires with respect to the industrial one in which the firms operates (De Marchi, 2002), makes it helpful to have a pattern of interaction with the external sources which is sustained over time. Through a deep interaction with each of the different sources, eco-innovators are able to share feed-backs with them, mutually adapt their understanding and reach an actual assimilation of external knowledge. As an illustration, one could just think about the need of having repeated interactions with both suppliers and customers for the firm to understand whether they could provide it with an actually green value chain for its EI. For these reasons, the extent to which firms draw deeply from their external sources should also positively impact on their EI.

If both the *breadth* and the *depth* of external search could be relevant for EI, the possibility that their exploitation could become at a certain stage counteracting should be also considered. With respect to technological innovations, this has actually been found (Laursen and Salter, 2006) and motivated by drawing on the attention-based theories of the firm (Simon, 1947; Ocasio, 1997; Koput, 1997). In brief, becoming too widely and/or too deeply reliant on external sources might entail for the firm a subtraction of organizational energies and cognitive attention from its ultimate innovative effort. In principle, this could equally happen for EI. However, two aspects require an empirical investigation in order to ascertain it. On the one hand, the balance between internal and external knowledge sources could be, in the case of EI, relatively more in favor of the latter, and thus exclude the possibility of an inverted U-shape pattern between *breadth/depth* and EI. On the one hand, given its inner systemic nature, in the case of EI, dealing with an increasing number of diverse knowledge sources could become more demanding, and thus more problematic, than drawing increasingly more from one of them

1.3 Empirical application

1.3.1 Econometric Strategy

The theoretical arguments presented in Section 1.2 will be tested through a set of econometric estimates. At first, the impact of the $BREADTH$ and $DEPTH$ of external sourcing on the firm's EI can be estimated through the following model, which includes a proper set of controls for each firm i ($CONTROLS$):

$$EI_i = \alpha + \beta_1 BREADTH_i + \beta_2 DEPTH_i + \gamma CONTROLS_i + \epsilon_i \qquad (1.1)$$

In a second moment, a variable which accounts for the role of cooperation in R&D, $COOP$, is included into equation (1.1) [3]:

[3] $COOP$ is added from the second model in order to avoid possible multicollinearity problem that might arise in including $COOP$ together with $BREADTH$ and $DEPTH$ from the first model. To be clear, this is just a scrupulous to cope with a correlation that might only in principle arise. If we look at the correlation matrix in

$$EI_i = \alpha + \beta_1 BREADTH_i + \beta_2 DEPTH_i + \beta_3 COOP_i + \gamma CONTROLS_i + \epsilon_i \quad (1.2)$$

In order to account for the potential non-linearity in the relationship between external knowledge sourcing and EI, the second model (1.2): will be augmented by including squared terms for both $BREADTH$ and $DEPTH$:

$$\begin{aligned} EI_i = \alpha + \beta_1 BREADTH_i + \beta_2 DEPTH_i + \beta_3 COOP_i + \beta_4 BREADTH_i^2 \\ + \beta_5 DEPTH_i^2 + \gamma CONTROLS_i + \epsilon_i \end{aligned} \quad (1.3)$$

Given the binary nature of the dependent variable, which will be described into the next section, the adequate model selected is a LOGIT one, which allows scrutinizing the relationship between external knowledge sourcing and the firm's probability to introduce an EI. As a robustness check, a PROBIT regression model will be also performed.

1.3.2 Dataset and variables

The empirical application is based on the Community Innovation Survey (CIS) for the period 2006-2008 and focus on manufacturing firms.[4] This CIS wave is the first one which collects systematically, into an ad hoc section, harmonized information on EI with a wide European coverage and has two main strengths. First, it directly provides data on the firms' EI output, without the need of resorting to indirect proxies like patent data (e.g. Griliches, 1998). Second, it allows for large scale analyses, such as the one we will carry out in the following for 11 countries: Bulgaria, Czech Republic, Germany, Estonia, Hungary, Italy, Lithuania, Latvia, Portugal, Romania, and Slovakia [5].

The CIS 2006-2008 defines EI in a way which substantially overlaps with the standard one provided by the "Measuring Eco Innovation" (MEI) project (see Section 1.2)[6].

Table 1.3 and at the VIF tests in Table 1.7, we can see that this problem is statistically not relevant.

[4]Data comes from the CIS 2006-2008 anonymized microdata dataset provided by Eurostat.

[5]Descriptive statistics by country of the dependent variable and the two main variable ($BREADTH$ and $DEPTH$) are available in the Appendix in Table 1.5 and Table 1.6.

[6]EI is defined as "a new or significantly improved product (good or service), process, organizational method or marketing method that creates environmental benefits compared to alternatives" where "the environmental benefits can be the primary objective of the innovation or the result of other innovation objectives" or "can occur during the production of a good or service, or during the after sales use of a good or service by the end user".

Table 1.1: Variables description

Variable	Description
ENVINNO	Dummy variable equal to 1 when at least one, out of nine categories of environmental innovations has been introduced by the firm
BREADTH	Number of external information sources the firms rely upon
DEPTH	Number of external information sources to which firms attribute a high degree of importance
COOP	R&D cooperation with cooperation partners (DUMMY)
EXPORT	Engagement into international markets (DUMMY)
INNOPOL	Existence of public support to firms' innovation activities (DUMMY)
lnTURNOVER	Natural logarithm of firms' turnover in 2006
MNC	Affiliation to a multi-national corporation (DUMMY)
POLSTR	Logarithm of country/sector CO_2 emission intensity in terms of Value Added in 2006
RD	Engagement in R&D activities (DUMMY)

Furthermore, it distinguishes nine types of EI: six related to environmental benefits emerging from the production of goods or services[7], and three concerned with the benefits emerging from the after-sales use of a good or service [8].

From this information I built the dependent variable $ENVINNO$, which is equal to one if at least one environmental innovation has been introduced by the firm and is equal to 0 otherwise.

Table 1.2: Variables descriptive statistics

Variable	N	mean	min	sd	max
BREADTH	15911	5,34	0	2,76	9
COOP	15911	0,30	0	0,46	1
DEPTH	15911	0,98	0	1,34	9
ENVINNO	15911	0,64	0	0,48	1
EXPORT	15911	0,70	0	0,46	1
INNOPOL	15911	0,23	0	0,42	1
lnTURNOVER	15911	13,53	-6,91	3,98	24,39
MNC	15911	0,15	0	0,36	1
POLSTR	15911	-0,85	-4,99	1,51	2,16
RD	15911	0,45	0	0,50	1

As for the independent variables in Table 1.1 and Table 1.2, I first draw on Laursen and Salter (2006) to capture the $BREADTH$ and $DEPTH$ of firm's external knowledge sourcing strategy.

The former counts the number of external information sources the firm relies upon for its innovation activities, out of the list of the nine indicated potential knowledge providers (i.e. suppliers; customers; competitors; consultants and private R&D institutes; universities; government or public research institutes; conferences, trade fairs, exhibitions; scientific journals and trade/technical publications; professional and industry associations). The latter instead counts the number of these external information sources to which the firm attributes a "high" degree of importance among the four listed options (i.e. not used, low, medium, high importance). From Equation(1.2) it is captured the extent to which the firm is engaged in formalized cooperation agreement with external partners with the use of a dummy variable, $COOP$, taking value 1 when the

[7]The following dimensions belong to this category: reduced material use per unit of output; reduced energy use per unit of output; reduced CO_2 'footprint' (total CO_2 production); replaced materials with less polluting or hazardous substitutes; reduced soil, water, noise, or air pollution and recycled waste, water, or materials.

[8]The following dimensions belong to this category: reduced energy us; reduced air, water, soil or noise pollution and improved recycling of product after use.

firm is formally engaged in cooperation agreement, either with business partners or with Universities or Research Organizations, and 0 otherwise.

It was then needed to control for those elements, which have been stressed to be EI determinants in previous literature, and that has been called $CONTROLS$ in Equation (1.1) to (1.3).

At first a dummy, RD, which captures whether the firm is engaged in internal R&D investment has been used[9].

The economic performance of the past is also accounted for, by including the logarithm of the turnover ($lnTURNOVER$) in the first year of the reference period, i.e. 2006. $COUNTRY$- and $SECTOR$- specificities in terms of market and technological opportunities and institutional settings are controlled for with the inclusion of a series of dummies [10]. Two characteristics related to the internationalization of the firm, which extant literature has considered to be important determinant of the EI performance (e.g. Cainelli et al., 2011, 2012) have been included: $EXPORT$, a dummy which reflects whether the company is engaged in international markets, and MNC which denotes whether the firm is an affiliate of a multi-national corporation.

Finally, given the relevance that policy and regulation aspects have been found in the empirical literature of the field, at first, I try to control for the role of policy intervention for innovation in general, with a dummy that captures whether the firm has received a public support for its innovation activities ($INNOPOL$). As for more specific regulatory aspects, unfortunately CIS data do not allow to directly control for those related to environmental policies at the firm level [11]. This issue has been overcome by exploiting EUROSTAT data on "Air emissions accounts by industry and households". In particular, as in some recent contributions (e.g. Costantini and Crespi, 2008), the logarithm of the CO_2 emission/Value Added ratio in each country/sector combination referred to the year 2006 has been adopted as a proxy for environmental policy stringency ($POLSTR$) [12].

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[9] Although available, I do not use the continuous variables for R&D expenditures. As they refer to the last year of the period (i.e. 2008), they could create endogeneity problems as the dependent variable refer to the entire period (i.e. 2006-2008).

[10] In order to control in a more punctual way for these specificities, as a robustness check COUNTRY*SECTOR interactions have been included.

Results of this robustness checks confirm the solidity of the models, and are presented in Table 1.8.

[11] To be clear, in the Section of the CIS on "Innovations with Environmental Benefits", a question on the role of regulation (either existing or expected) is included. The formulation of the question, however, does not allow me to include this variable in our regressions, as it covers only those firms who introduced an environmental innovation, and it could generate endogeneity problems in the regressions.

[12] Robustness checks on different years for emissions and value added (2006-2008

As a robustness check, a dummy variable ($EAST$) capturing those Countries belonging to the Eastern Europe has been added to the full specified model. This inclusion has not altered the results and the variable was found to be negative and significant. At the sake of parsimony it has been excluded from my analysis, because it was not improving the explanatory power of the model, as the Pseudo Squared R after its inclusion remained unaltered. The correlation matrix (see Table 1.3) and the Variance inflation factor (see Table 1.7) do not reveal collinearity problems in the regressors selected.

1.4 Results

The main research hypothesis about the importance of knowledge sourcing is strongly confirmed.

Once the role of the firm's internal and external predictors of EI is controlled for (Equation (1.1)), knowledge sourcing appears as a firmly significant EI driver. On the one hand, the wider the array of knowledge sources the firm draws on ($BREADTH$), the greater is the firm's coverage of the multiple need of knowledge that EI requires, and the more probable is its introduction. On the other hand, although with a lower impact, the chance to be an eco-innovator also increases with the competences that the firm acquires from a deep interaction with its external knowledge sources ($DEPTH$).

The inclusion of cooperation in R&D (Equation (1.2)) is relevant, as $COOP$ is positive and significant, and, moreover, is not altering the results of the previous Model.

The test for non-linear effects (Equation (1.3)) of external knowledge also shows that its impact on EI is not unbounded, at least as far as the breadth of knowledge sourcing is concerned. More specifically, the benefit of a diffuse sourcing strategy stops increasing after a certain level ($BREADHT^2$ is significantly negative). As it happens with technological innovations, an excessive and not profound resort to multiple knowledge sources can create redundancy and/or inconsistent signals, which could make the firm hesitant to step into EI.

The negative sign of $BREADTH^2$ required to implement a further analysis, to assess whether the negative coefficient of the quadratic term ($BREADHT^2$) offsets, after a certain threshold, the positive effects of $BREADTH$. Should it be the case, it would lead not generally to diminishing returns but specifically to negative returns.

emissions and 2006 value added; 2003-2005 emissions and 2003-2005 value added) have been performed.

Table 1.3: Variables correlation matrix

id	Variable	1	2	3	4	5	6	7	8	9	10
1	ENVINNO	1									
2	BREADTH	0,25	1								
3	DEPTH	0,15	0,40	1							
4	RD	0,25	0,36	0,19	1						
5	COOP	0,20	0,30	0,22	0,30	1					
6	lnTURNOVER	0,18	0,17	0,12	0,14	0,19	1				
7	MNC	0,11	0,09	0,00	0,09	0,19	0,22	1			
8	EXPORT	0,19	0,18	0,09	0,30	0,21	0,23	0,22	1		
9	INNOPOL	0,11	0,23	0,14	0,29	0,24	-0,01	-0,02	0,14	1	
10	POLSTR	-0,10	-0,03	-0,02	-0,13	-0,03	-0,06	-0,01	-0,12	-0,06	1

Table 1.4: Estimation results

VARIABLES	(I)	(II)	(III)
BREADTH	0.116***	0.107***	0.273***
	(0.00778)	(0.00784)	(0.0271)
DEPTH	0.0883***	0.0735***	0.0938***
	(0.0172)	(0.0173)	(0.0339)
$BREADTH^2$			-0.0173***
			(0.00267)
$DEPTH^2$			-0.00467
			(0.00708)
COOP		0.469***	0.478***
		(0.0494)	(0.0496)
RD	0.402***	0.347***	0.322***
	(0.0443)	(0.0446)	(0.0451)
lnTURNOVER	0.0200***	0.0193***	0.0206***
	(0.00671)	(0.00669)	(0.00673)
POLSTR	0.0127	0.0113	0.0125
	(0.0225)	(0.0226)	(0.0226)
MNC	0.302***	0.233***	0.241***
	(0.0591)	(0.0598)	(0.0599)
EXPORT	0.251***	0.238***	0.234***
	(0.0453)	(0.0453)	(0.0455)
INNOPOL	0.195***	0.119**	0.125**
	(0.0494)	(0.0503)	(0.0504)
Constant	-0.539***	-0.483***	-0.790***
	(0.13)	(0.131)	(0.141)
Sector Dummies	Yes	Yes	Yes
Country Dummies	Yes	Yes	Yes
Pseudo R^2	0.1627	0.1675	0.1697
Log Pseudo-Likelihood	-8703.3982	-8649.0873	-8626.4246
Prob> Chi^2	0	0	0
Observations	15.919	15.911	15.911

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

From Figure 1.1, it can be identified a maximum point in the function (graphically for values of $BREADTH$ above 8), below which $BREADTH$ seems to negatively affect EI, as the function starts decreasing. By testing for that, on the contrary, the conclusion that no negative returns are at stake can be derived [13].

On the other hand, going back to the interpretation of the estimation results, whatever increase in $DEPTH$ turns into an increase in the probability of introducing an EI ($DEPTH^2$ is not significant), suggesting the pervasive (although lower) benefits of a sustained pattern of interaction with the outer environment for a firm which aims at entering the green realm [14]. Coming to the controls, all the variables are behaving as I expected.

The "technology push" played by firmÂťs engagement in R&D activities is a good and significant predictor of EI. Also "market pull" kind of determinants have resulted as being important: past economic performance ($lnTURNOVER$) is positive and significant. "Firm specific characteristics" such as sector, country, exporting activities ($EXPORT$) and being a multinational affiliate (MNC) are also key determinants for EI.

Lastly, the "regulatory push" is confirmed in the case of the existence of an innovation policy ($INNOPOL$ positive and significant), while the proxy for the stringency of the policy is not significant. This last element is not surprising, as having included in all the models both Country and Sector dummies, should have cleaned the data from country and sector specific policy stringencies. This is however not implying at all that policy does not play a role in spurring EI.

[13] This result has been derived by calculating algebraically the turning point by equaling to zero the first derivative of the function. This function is constructed by implementing the margins of the logit model in equation (1.2), having as a dependent variable $ENVINNO$, and for the explanatory variables, all the values are taken at their means, a part from $BREADTH$, which takes continuous values. The first derivative of this function has been computed to calculate the condition under which it equals 0, i.e. when the ratio between β_1 $BREADTH$ and β_2 $BREADTH^2$ is equal to zero. Accordingly, what emerges is that the maximum point of the function lays at value 8.32 of the independent variable, with a confidence interval which varies from 7.14 to 9.45. If we consider that the $BREADTH$ ranges from 0 to 9, I can conclude that the function does not show actually negative returns, as in the confidence interval the function is not significatively different from 0. This means that the negative value of the quadratic term has to be interpreted as a sign of only decreasing returns, but no negative effect are depicted. I stress this result, as it is different from what emerged in previous study on technological innovations (Lauren and Salter, 2006).

As further test for the presence of decreasing returns,$BREADTH$ has been split into 4 groups, according to the number of external sources the firm is relying upon, and, taking as a benchmark the class $NOBREADTH$ (in which 0 external sources are exploited), a Logit regression for the Model (1.3) has been performed. Once again, the decreasing returns of $BREADTH$ are confirmed, see Table 1.9 in the Appendix.

[14] As no curvilinearity in $DEPTH$ is depicted in the estimation results, no further test is needed to disentangle it.

1.5 Conclusions

In spite of several common elements, *EI* are substantially different from "standard" technological and non-technological innovations. The possibly more systemic nature has been confirmed by the recent studies that extend the analytical tool-box of innovation studies to the investigation of EI (e.g. De Marchi, 2012). This result is supported by the evidence on the importance of external knowledge for the firm's EI performance. Apart from these works, the extent to which firms can actually organize in order to benefit from external knowledge has not been investigated yet.

Although in a not very integrated way, the adoption of specific strategies of knowledge sourcing, have been found to impact on the firms' innovativeness.

In trying to fill this gap, the extant literature on the search patterns for external knowledge of innovative firms has been exploited (Laursen and Salter, 2006) and, as a value added, the standard innovation literature has been applied to the realm of EI. The econometric strategy of the empirical application has been chosen consistently with the nature of the dependent variable, and makes use of the systematic evidence, which has been collected through the CIS 2006-2008 wave with respect to eleven countries. Drawing on external knowledge, by devising (implicitly or explicitly) patterns of knowledge search which are broad and deep increases the firm's chance to become an innovator. At first sight, open entrepreneurial strategies and open-innovation friendly policy should find scope to increase the *EI* performance of the firms and their externalities on the economic system.

Furthermore, as in the case of non-EI, knowledge sourcing is not completely unbounded: an excessive breadth of external sources become problematic to handle and shows decreasing returns, but it does not become detrimental, contrarily to technological innovation. Cooperation in R&D is also confirming my expectation of playing a key role in spurring *EI*, and this is coherent with previous literature in the field (e.g. De Marchi, 2012). Lastly, the analysis of the set of determinants I built coherently with previous literature can confirm my research expectations.

All in all, some of the building blocks of the open innovation mode seem to work also in the case of *EI*, and this make of the "open eco-innovation mode" an important source of inspiration for further analysis and policy efforts towards more sustainable patterns of development. A further and interesting step, would be to look at the elements which work in-between the absorption of external knowledge within firms [15].

[15] I am currently working on this further step in a paper jointly co-authored with

Appendix

Figure 1.1: Plot of the predicted probability of EIs on BREADTH

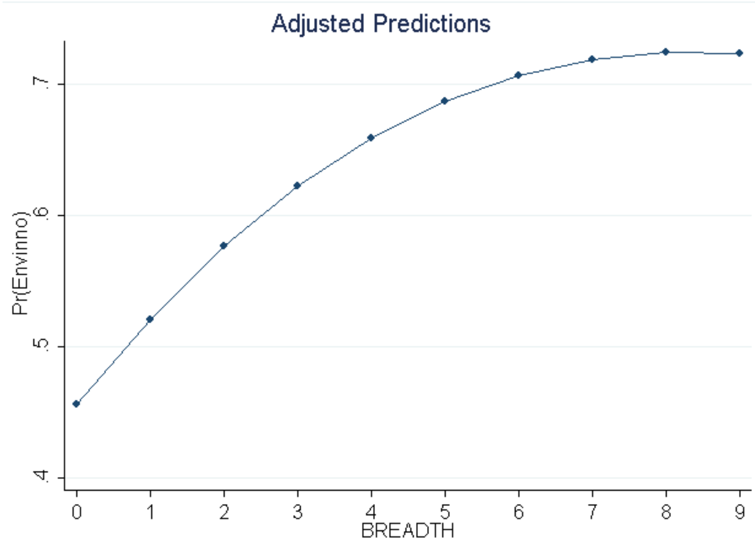

Table 1.5: Distribution of the EI, BREADTH and DEPTH by Country

	EI			
COUNTRY	0	1	Total	Perc. values >0
BG	1935	727	2662	27%
CZ	278	1179	1457	81%
DE	648	1683	2331	72%
EE	500	804	1304	62%
HU	194	582	776	75%
IT	1200	1900	3100	61%
LT	100	224	324	69%
LV	64	91	155	59%
PT	340	1741	2081	84%
RO	377	1020	1397	73%
SK	80	244	324	75%

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Table 1.6: Distribution of BREADTH and DEPTH by Country

BREADTH												
COUNTRY	0	1	2	3	4	5	6	7	8	9	Total	Perc. values >0
BG	123	295	302	460	330	228	225	173	76	450	2662	95%
CZ	34	33	43	70	108	167	209	230	177	386	1457	98%
DE	608	17	33	64	126	194	240	226	253	570	2331	74%
EE	20	56	130	144	202	238	210	158	60	86	1304	98%
HU	26	24	28	46	81	87	100	113	121	150	776	97%
IT	30	232	267	311	414	382	369	398	223	474	3100	99%
LT	13	33	26	33	41	41	40	25	29	43	324	96%
LV	13	3	10	11	17	25	24	21	11	20	155	92%
PT	27	134	110	136	205	252	290	276	167	484	2081	99%
RO	40	51	86	91	162	237	197	140	88	305	1397	97%
SK	5	11	19	31	40	47	42	42	35	52	324	98%
DEPTH												
COUNTRY	0	1	2	3	4	5	6	7	8	9	Total	Perc. values >0
BG	1670	413	317	136	61	32	17	6	4	6	2662	37%
CZ	596	391	248	125	55	21	11	7	3	0	1457	59%
DE	1121	607	328	151	76	27	14	6	0	1	2331	52%
EE	668	416	130	58	20	10	2	0	0	0	1304	49%
HU	261	203	151	84	39	21	11	4	2	0	776	66%
IT	1638	876	351	133	64	18	8	7	1	4	3100	47%
LT	187	71	36	16	7	6	0	1	0	0	324	42%
LV	74	29	26	17	5	3	1	0	0	0	155	52%
PT	985	489	296	159	78	35	20	10	2	7	2081	53%
RO	599	333	204	133	69	29	10	8	2	10	1397	57%
SK	135	92	48	36	9	4	0	0	0	0	324	58%

Table 1.7: Variance inflation factor of the regressors

Variable	VIF	1/VIF
BREADTH	1,37	0,727353
RD	1,33	0,752681
COOP	1,25	0,801662
DEPTH	1,21	0,825091
EXPORT	1,2	0,834456
INNOPOL	1,16	0,861648
lnTURNOVER	1,14	0,879183
MNC	1,12	0,896318
POLSTR	1,03	0,972957
Mean VIF	1,2	

Table 1.8: Logit regression with Country*Sector interaction matrix

VARIABLES	(1)	(2)	(3)
BREADTH	0.118***	0.109***	0.280***
	(0.00786)	(0.00791)	(0.0275)
DEPTH	0.0888***	0.0739***	0.0972***
	(0.0173)	(0.0174)	(0.0338)
$BREADTH^2$			-0.0177***
			(0.0027)
$DEPTH^2$			-0.00531
			(0.00699)
COOP		0.478***	0.487***
		(0.0498)	(0.05)
RD	0.413***	0.357***	0.331***
	(0.0448)	(0.0451)	(0.0456)
lnTURNOVER	0.0208***	0.0201***	0.0215***
	(0.0067)	(0.00667)	(0.00671)
POLSTR	-0.0922	-0.0398	0.0337
	(0.96)	(0.966)	(0.956)
MNC	0.298***	0.228***	0.234***
	(0.0594)	(0.0602)	(0.0603)
EXPORT	0.261***	0.248***	0.244***
	(0.046)	(0.046)	(0.0461)
INNOPOL	0.189***	0.112**	0.118**
	(0.0498)	(0.0508)	(0.0509)
Constant	-0.87	-0.773	-1.029
	(0.89)	(0.896)	(0.887)
Sector Dummies	Yes	Yes	Yes
Country Dummies	Yes	Yes	Yes
Sector*Country	Yes	Yes	Yes
Pseudo R^2	1.675	1.724	1.747
Observations	15,919	15,911	15,911

Robust standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 1.9: Robustness check on curvilinearity in BREADTH through classes

VARIABLES	LOGIT
BREADTH1_3	0.654***
	(0.0923)
BREADTH4_6	1.005***
	(0.0899)
BREADTH7_9	1.181***
	(0.0922)
DEPTH	0.1000***
	(0.0339)
$DEPTH^2$	-0.00533
	(0.00709)
COOP	0.477***
	(0.0495)
RD	0.329***
	(0.0449)
lnTURNOVER	0.0207***
	(0.00677)
POLSTR	0.0131
	(0.0226)
MNC	0.243***
	(0.0599)
EXPORT	0.234***
	(0.0454)
INNOPOL	0.123**
	(0.0503)
Constant	-0.893***
	(0.152)
Sector Dummies	Yes
Country Dummies	Yes
Observations	15.911

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Chapter 2

Beyond inducement in climate change: does environmental performance spur environmental technologies? A regional analysis of cross-sectoral differences

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[1]This paper has been accepted for publication in Ecological Economics. It has been written during a Research Visiting period at GREDEG-CNRS Sophia Antipolis (France).

Abstract

This paper contributes to the debate on the inducement of environmental innovations by analysing the extent to which endogenous inducement mechanisms spur the generation of greener technologies in contexts characterized by weak exogenous inducement pressures. In the presence of a fragile environmental regulatory framework, inducement can indeed be endogenous and environmental innovations may be spurred by firms' reactions to their direct or related environmental performance. Cross-sector analysis focuses on a panel of Italian regions, over the time span 2003-2007, and is conducted by implementing zero-inflated regression models for count data variables. The empirical results suggest that in a context characterized by a weak regulatory framework, such as the Italian one, environmental performance has significant and complementary within- and between-sector effects on the generation of green technologies.

JEL Classification Codes: JEL Classification Codes: O33, Q53, Q55, Q56, R11

Keywords: Green technologies, Environmental Performance, Regional NAMEA, Technological innovation, Knowledge production function

2.1 Introduction

The economic analysis of environmental issues has received increasing attention over the last decades. Within the wide body of literature on the subject, the dynamics of the creation of environmental innovations has recently become a key topic, due also to the identification of these new technologies as a means of restoring the competitiveness of advanced countries which has been harmed by the economic crisis. Their emergence is indeed supposed to bring about new jobs and new perspectives for economic growth.

In this respect, an investigation of the determinants of green innovations may provide useful input to policymakers when designing targeted measures aiming, on the one hand, at reducing the environmental impact of production activities and, on the other, at fostering technology-based competitiveness.

Most of the literature analysing determinants of environmental innovation has been grounded on the induced innovation approach according to which stringent environmental regulation may exert an incentive to firms to introduce innovations, for instance, allowing the polluting standards exogenously set up by policymakers to be met (Brunnermeier and Cohen, 2003; Rennings and Rammer, 2011; Rennings and Rexhuser, 2011).

This paper aims at contributing to this strand of literature by adopting a different and yet complementary perspective on the inducement mechanism. We investigate the extent to which, in a context with a weak environmental regulatory framework, an inducement of environmental technologies can still be at stake. In such a framework, inducement could indeed be endogenous rather than exogenous. Instead of investigating the direct relationship between an inducing factor (mainly an environmental policy) and the generation of green technologies, as previous literature has done, we posit that it is important to understand if and to which extent such endogenous mechanisms are set in motion as a response to environmental performance. In articulating this hypothesis, we provide an interpretation of how those endogenous mechanisms work by appreciating the distinction between direct inducement and that exerted by related sectors.

To understand the latter, we need to stress the differences and complementarities between the adoption of greener technologies and their generation processes. For the latter, we argue that inducement mechanisms are likely to work through user-producer dynamics based on the derived demand of polluting agents for cleaner technologies rather than through their direct innovating efforts. We put particular emphasis on the importance of vertical linkages and the role of derived demand in stimulating the generation of green technologies since environmental innovations may be endogenously pulled by the derived demand of vertically related sectors featuring bad environmental performance. To test for this, we implement a synthetic measure of vertical relatedness across sectors based on input-output tables.

Cross-sectoral analysis is carried out on a panel of Italian regions observed over the time span 2003-2007, and is based on matching of the regional National Accounting Matrix with Environmental Accounts (henceforth NAMEA) data, patent data and regional economic accounts. The econometric results, obtained by implementing a zero-inflated binomial model for count data variables, identify interesting and persistent patterns of inducement for different classes of emissions. Environmental performance of vertically related sectors, proxied by emission intensities in terms of value added, exerts a positive impact on the generation of green technologies. This would support the hypothesis that sectors with higher levels of green innovativeness are stimulated to generate green knowledge by the demand coming from vertically related sectors with bad environmental performance.

The rest of the paper is organized as follows. Section 2 articulates an induced innovation framework to the analysis of the determinants of the creation of green knowledge at the sectoral and regional level and constructs the working hypothesis. Section 3 outlines the empirical context of the analysis while Section 4 presents the data, methodology and variables. In section 5, we show the results of the econometric analyses and the main robustness checks we implemented. We provide conclusions and points for discussion in Section 6.

2.2 Induced technological change and derived demand for environmental innovations

The inducement hypothesis in climate change has been largely investigated in the domain of environmental economics. This hypothesis identifies environmental regulation as a driver for environmental innovations, resting upon the traditional Hicksian argument that "A change in the relative prices of factors of production is itself a spur to invention, and to invention of particular kind - directed to economizing the use of the factor which has become relatively expensive" (Hicks, 1932: 124-125) [2].

[2]Habbakuk (1962) provided support to this hypothesis showing how, in American and British historic evidence through the nineteenth century, labour scarcity pushed firms to generate and introduce labour-saving technologies. The formal analysis pro-

This strand of literature points to the moderating role played by regulation on the generation of green technologies. A stringent policy is treated as an additional cost that increases total production costs by changing the relative factor prices. This induces firms to engage in innovation activities aimed at reducing the increased cost, e.g. by developing emission-saving technologies [3]. The incentives are engendered outside the production system, i.e. in the institutional system and will for this reason be labelled as exogenous in this paper. The correlation between environmental regulation and technological change has been empirically investigated either by using patent data to test whether regulation affected knowledge generation [4] (e.g. Lanjouw and Mody, 1996; Brunnermeier and Cohen 2003; Jaffe and Palmer, 1997; Popp, 2006) or by using survey data to test whether regulation pushes and/or pulls environmental innovations (e.g. Frondel et al, 2008; Horbach et al., 2012, Rennings and Rammer, 2011; Rennings and Rexhäuser, 2011; for a review see Del Rio, 2009). In both cases, evidence confirms that regulation exerts a positive effect on innovation.

The outcome of such inducement mechanisms cannot however be taken for granted. The public nature of innovation and the appropriabil-

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vided by Kennedy (1964) and Samuelson (1965) consists in the construction of an innovation possibility frontier, with the typical shape of a production possibility frontier, along which the trade-off between labour-saving and capital-saving innovations can be traced. The relative costs of capital and labour shape the isorevenue that enables identification of an optimum direction of technological change (Binswanger andRuttan, 1978). The approach has been criticized for the lack of microeconomic foundations by Salter (1966), but remains one of the cornerstones of the economics of innovation. Ruttan (1997 and 2001) has shown that technological change is characterized by a strong directionality that can be represented in terms of changes in the output elasticity of production factors.

[3]Pindyck (1979), and Atkeson and Kehoe (1999), shed light on the question as to what extent energy and capital are complementary or substitutes by concluding that in the short run these are complements while in the long run they are substitutes.

Accordingly, an increase in the price of energy (factor of production) in the long run induces technological change (Jaffe and Stavins, 1995).

[4]In this perspective, an increase in pollution abatement expenditures, taken as a proxy for the stringency of environmental regulation, exerts a positive effect on granted patents in environmental fields (Lanjouw and Mody, 1996) and on patent applications in environmental technologies (Brunnermeier and Cohen, 2003). Conversely, by using the same proxy for environmental regulation, Jaffe and Palmer (1997) found a positive effect only on innovation inputs, measured by R&D expenditure, while no significant effect was found on overall patents.

The literature has also focused on specific environmental patents, e.g. on the effect of climate change policies on renewable energy patents (Johnstone, 2010a), on some specific regulations, e.g. the Clean Air Regulation on NO_x and SO_x (Popp, 2006) and on the role of the perception of stringent environmental policies (Johnstone et al., 2012). In all these cases, confirmation of the inducement hypothesis has been found.

ity regime does indeed create a positive externality, which is translated into innovation efforts that are lower than the social optimum. Conversely, pollution is a case of negative externality, the social costs of which are spread over the entire society, so that firms pollute more than the social optimum level. Without policy intervention "firms pollute too much and innovate too little compared with the social optimum" and investments in green technologies are in the end too low as "the two market failures are mutually reinforcing" (Johnstone et al., 2010b: 9).

The need for environmental regulation is also supported by the Porter hypothesis (Porter and van der Linde, 1995) in its different versions [5], and empirical evidences underline the positive effect of regulation over firms' competitiveness, e.g. in terms of increased trade for environmental technologies (Costantini and Mazzanti, 2012).

Moreover, the regulatory push/pull framework may have different effects across different typologies of environmental innovations (Rennings and Rammer, 2009; Rexhäuser and Rammer, 2013) and different policy frameworks [6] What is more, the stringency, predictability, flexibility, incidence and depth of the policy instruments impact on the effort and direction of the innovations (Johnstone et al., 2010b) although the measurement of these elements is not an easy task (Kemp and Pontoglio, 2011).

In contexts characterized by weak environmental regulatory frameworks and/or barriers to policy enforcement, the inducement may come from within the economic system (endogenous) rather than from the institutions (exogenous).

A step forward in the identification of the endogenous incentive for firms to generate green technologies is represented by the literature on corporate social responsibility (CSR)[7]. As remarked by Orlitzky et al.

[5]This hypothesis suggests that stringent environmental regulations, under certain circumstances, may trigger innovations which lead to innovation offsets that are going to improve firm competitiveness. According to the assumptions on the effect of regulations, the Porter hypothesis can be split into a "narrow" a "weak" and into a "strong" version (Jaffe and Palmer, 1997). This hypothesis remains controversial in its empirical investigation (see, for instance,Lanoie et al., 2011). Without going into the details of this literature, it is important for us to highlight its content and the fact that this idea challenges the one that regulation may be detrimental on firms' and countries' competitiveness, thus encouraging production to be moved to countries with lower environmental standards. This is known as pollution haven hypothesis.

[6]Market-based instruments such as taxes on the emissions or tradable permits have indeed stronger impacts on innovations than direct regulation (e.g. Popp et al., 2009) may generate different innovative outcomes (Popp et al., 2009).

[7]The origins of this approach date back to the 1950s and it has been developed to accommodate the traditional firms' maximization objectives and the idea that corporations play a role in society (see Lee (2008) for an exhaustive review). In the last

(2011), although the CSR concept appears to be a multifaceted one, the assumption that environmental responsibility is a key part of it is less controversial (Hart, 1997).

Accordingly, factors such as moral appeal, sustainability and reputation are particularly relevant in shaping the choice of firms to adopt environment-friendly behaviour. The generation of green technologies may allow firms to align the target of lowering the environmental impact of the production process with the target of increasing technology-based competitiveness. The reduction of production costs becomes a potential side effect stemming from the generation of green technologies whereas the main inducing factor relates to the likelihood of improving firms' performance through market evaluation.

These positive business performance effects of firms' environmental innovation strategies have been systematically assessed by Ambec and Lanoie (2008) who explicitly analysed the channels through which environmental practices are improving firms' financial performance. On the one hand, environmental performance can increase revenues via a better access to "green" markets, via a product differentiation strategy and via entering a market for their pollution control technologies. On the other hand, it can reduce costs in the following categories: "a) risk management and relations with external stakeholders; b) cost of material, energy and services; c) cost of capital and d) cost of labour" (Ambec and Lanoie, 2008: 46).

To sum up, consistently with the broader CSR approach, environmental responsibility may affect firms' financial returns by allowing the development of new markets, the increase of the market value of publicly traded firms, the reduction of consumer boycotts and the attraction of active consumers [8]. Moreover, a proactive environmental management may also reduce the risks associated with potential regulatory and legal

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decades, this approach has successfully elaborated a framework that articulates the link between CSR and corporate financial performance (CFP) (Margolis and Walsh, 2003; Orlitzky et al., 2003; Porter and Kramer, 2002 and 2006, Kotler and Lee, 2005).The recent developments of strategic management theories draw upon the extension of the stakeholder theory, as proposed by Freeman (1984). Unlike traditional approaches, in this one, firms' objectives should not only take into account shareholders, but also stakeholders, thus involving employees, local communities, governments and customers.

Consequently, the social and economic goals of a corporation are strictly intertwined. The grafting of the CSR onto the stakeholder theory has allowed the scope of the concept of CSR to be widened to include environmental responsibility, diversity, affirmative action, transparent accounting, etc. (Jones, 1995; Clarkson, 1995; Berman et al., 1999).

[8] This makes CSR closely related to the concept of sustainable consumption (Sanne, 2002; Gilg et al., 2005).

actions (Lee, 2008).

The inducement hypothesis in climate change, by stressing the impact of changes in the regulatory framework on firms' costs, can thus be read as an application of a price-inducement argument to the price of polluting production technologies (Lichtenberg, 1986; Antonelli, 1998). The mechanisms through which the adoption of an environmental regulation is translated into an increase in environmental innovations are to our knowledge still not fully explored. Indeed, it is worth stressing that patent statistics are a reliable proxy of inventive activity, but not of adoption, since polluting firms under a stringent regulation may be willing to adopt green technologies, but they do not always have the necessary competences to generate them. In such cases, the pressure from regulation can engender a derived demand of green technologies.

The interplay between the classical inducement mechanism and the derived demand pull dynamics (Schmookler, 1957) allows the relevance of vertical linkages to be stressed (as in Cainelli and Mazzanti, 2013) and gives rise to an extended inducement hypothesis. Downstream firms confronted with stringent regulatory frameworks resort to upstream firms for the supply of new and more environment-friendly technologies in the production process. A stringent regulatory framework thus alters the relative prices of production processes, inducing firms to redefine the characteristics of the intermediate goods they buy on factors' markets [9]. The interactions between users and producers therefore matter in shaping the ultimate effects of the inducement mechanism, in a way that the generation and the adoption of new technologies become strictly complementary (von Hipple, 1988; Lundvall, 1992; Nelson, 1993; Antonelli, 2006; Castellacci, 2008).

In view of the arguments articulated so far, we are now able to spell out our working hypothesis. Inducement mechanisms play a crucial role in the generation of new technological knowledge, especially in the domain of green technologies. The interplay between price-inducement and derived demand-pull mechanisms brings vertical linkages to the centre of our analysis, where the generation of new technologies is likely to be triggered by the derived demand of polluting firms for technologies that improve their environmental performance.

However, the relevance of these inducement mechanisms is context-specific. In contexts characterized by weak regulations and ineffective policy interventions, the inducement mechanism is more likely to be set in motion by endogenous mechanisms, i.e. internal to the economic sys-

[9] Alternatively, one can look at the inducement mechanisms as the result of the movement of firms across the Lancastrian space representing the features of the intermediate goods they employ in the production process (Lancaster, 1966).

tem, rather than by the exogenous ones, i.e. lying in the policy realm. In particular we hereby mainly consider as endogenous mechanisms the following co-occurring mechanism: the social responsibility of firms that are responsible for the emissions of pollutants and the opportunistic behaviour of pre-emptive response to a future regulation.

The paper raises the basic question as to what extent an inducement of environment-related inventing activities may also be depicted in those contexts characterized by weak (exogenous) policy inducements. We further draw on this intuition and test on the one hand whether, in the presence of weak policy inducement, some endogenous inducement mechanisms are at stake. In particular, we analyse on the one hand whether the generation of green technologies is directly affected by regional and sectoral environmental performance. On the other hand, we test whether vertical relationships are important in that environment-related inventing activities may benefit from an endogenous inducement from downstream firms operating in vertically related sectors To the best of our knowledge, no previous attempts have been made to investigate the inducement environmental region/sector composition plays on the generation on knowledge.

In line with the local dimension of stakeholder theory, the hypothesis we are testing is that firms located in highly polluting regions and belonging to strong polluter sectors will be more prone to inducing the generation of green technologies in upstream sectors, as compared with others, either as a side-effect of their expectation of future stringent regulations or as an effect of increasing environmental responsibility. In other terms, we test whether sectoral environmental performance in the sampled regions is likely to affect sectoral generation of green technologies. More precisely, we hypothesize that environmental performance generated by closely (vertically) related sectors affects green innovative activities whereas the sectors in which the generation of green technologies occurs are also likely to be characterized by better environmental performance.

2.3 Empirical context

As outlined in the previous section, the strand of literature on the induced innovation hypothesis in climate change basically tests the existence of a link between environmental regulation and green technological change. We have argued that in an environmental policy weak context, it may not be appropriate to focus on the regulatory framework since it is more likely that only endogenous inducement mechanisms will be set in motion.

Although Italy presents one of the higher levels in the amount of environmental taxes[10], we have chosen this country as an environmental policy weak context for the reasons we are now going to discuss.

Although Italy is part of a broader European environmental policy framework, country heterogeneities are still at stake and depend on the way policies are implemented. Any policy framework may vary according to its characteristics such as its stringency, certainty, incidence, depth and flexibility (for a discussion, see Haščič et al, 2009) and what makes the difference in terms of inducement is not the existence of an environmental policy per se, but relative policy stringency. In this respect, Italy is one of the countries reporting lower levels in the indicator of policy stringency[11] (Haščič et al, 2009).

Furthermore, higher levels of corruption reduce the stringency of an environmental policy (Damania et al., 2003), and Italy is one of the European countries performing worst in terms of controls of corruption [12]. The country also presents lower levels in stability and transparency [13] of the environmental policy compared with other OECD countries (Johnstone

[10]Italy is the third country, after Germany and United Kingdom, in the level (in absolute terms) of environmental taxes in ranking Eurostat data on Environmental tax revenue for European countries in the last available year (2011) and its position in terms of GDP lies in the middle of the rank. These data include all environmental taxes in the following fields: Energy, Transport, Pollution and Resources (Eurostat: Environmental tax revenue). Since high energy prices can induce green innovations (e.g. Popp, 2001), and the presence of high energy taxes (as is the case of Italy) raises the costs of energy consumption, we will control for the role of energy consumption as a robustness check in our empirical analysis, to be sure that our assumption of weak policy is not engendering a bias in our estimation deriving from omission of the role of energy consumption. See estimation results in Table 2.7.

[11]The study by Haščič et al. (2009) uses data from the World Economic Forum's Executive Opinion Survey to assess both the level of flexibility and stringency across a set of selected countries in the period 2001-2006. For both indicators, which are highly correlated, Italy is performing averagely worse than the other European Countries, with an index of 4.95 for stringency and 3.77 for flexibility in a Likert scale ranging from 1 to 7 (with 7 being the most stringent regime). If we think of the well known case of the Ilva steel production plant in Taranto (Italy), we can find an example which corroborates our assumption of weaknesses (to be fair) in the enforcement of an Italian environmental policy.

[12]In ranking data of the World Bank - Worldwide Governance Indicators- we see that Italy reports for 2011 (the last year available) a value in the indicator on the control of Corruption of -0.007, which is greater only than those reported by Romania and Greece (for European Union countries). This index ranges from -2.5 and + 2.5 and captures the "perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as "capture" of the state by elites and private interests". For details on the construction of this index, refer to Kaufmann et al. (2010).

[13]In a subsequent study, Johnstone et al. (2010b) in using the same WEF data, presented a rank of countries according to an index on the policy stability and transparency and Italy performs badly also in this last respect.

et al., 2010b). Lastly, it does not report many environmental instruments, with the exception of the EU ETS ("European Trading Scheme") sectors which fall under the EU ETS Directive, and the relatively high level of environmental taxes we outlined before.

When assessing the role of the policy framework in the Italian context on emission performance, a further confirmation of the weakness of the Italian regulation has emerged in the literature. The insight is that manufacturing "has also not adapted to the new climate change policy scenario, and even the environmental Italian policy as a whole has somewhat lagged behind other leading countries in terms of policy efforts". (Marin and Mazzanti, 2013: 22).

For these reasons, it is more likely that, in such a context, pressures - if any - to improve the environmental performance emerge within corporate boundaries rather than from external policy constraints.

The Italian policy weak empirical context justifies our decision to select this country, in order to test our hypothesis on whether the environmental performance, rather than direct policy measure, induces green technological change, or, in other terms, whether environmental performance (both direct and related) is correlated with the generation of green knowledge. The focus on Italy is even more relevant if we look at its overall trends in air emissions. In terms of total Greenhouse Gases (GHG), emission is indeed still far from reaching the 2012 Kyoto target, with its overall GHG emissions reduced by only 3.5% [14](UNFCCC). Most importantly, it is the European country in the G8 group that is performing worst [15], and it has reached a reduction in GHG which is even lower than the European Union average[16].

The choice of an appropriate country-case is however not enough since an appropriate level of analysis has to be chosen. Intuitively, the best level of analysis would be the firm level one, but the lack of data availability at this level calls for an alternative solution.

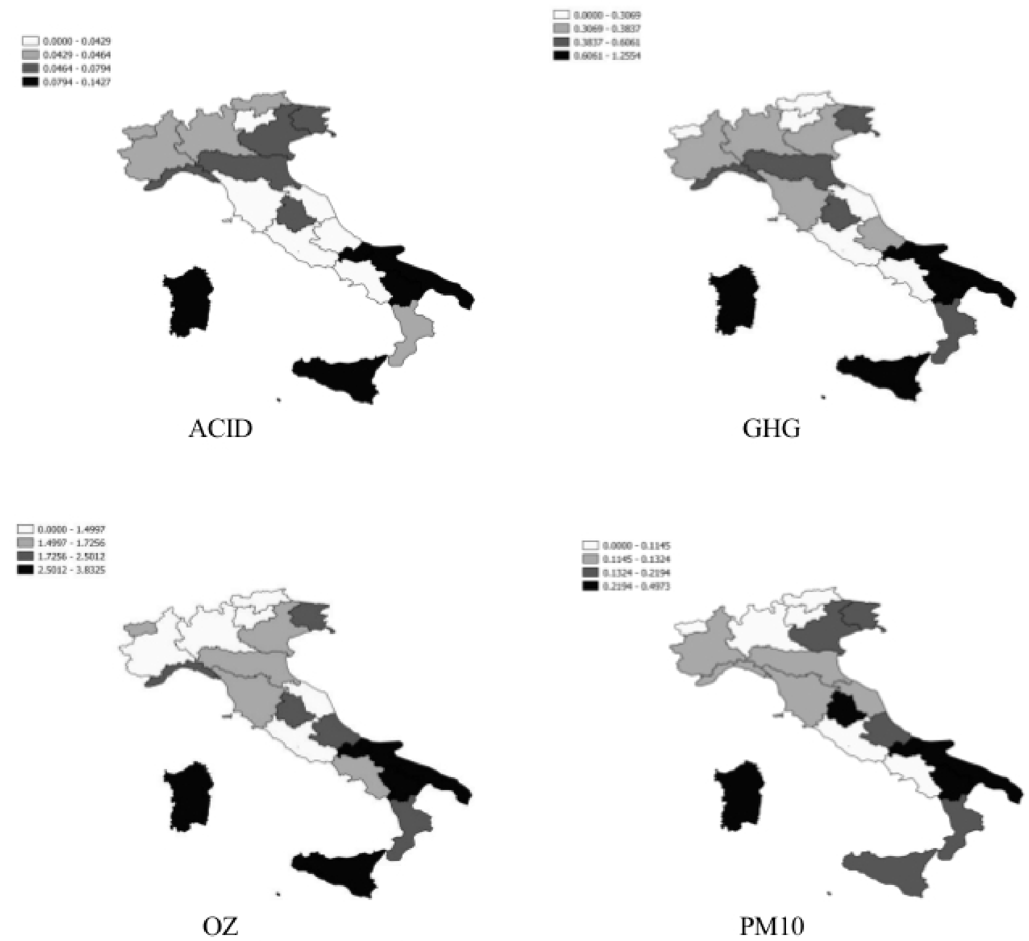
If we look at the regional composition of air emissions in Italy (Figure2.1), we find evidence of strong and persistent regional differences which sug-

[14]The target for Italy was to reach by 2012 a total Gg of CO_2 equivalent in GHG equal to 92% of the emissions recorded in 1990. The 3.5% reduction refers to the year 2010, with 1990 as a reference year.

[15]Indeed, France has achieved a 6% reduction, United Kingdom, 22.5% and Germany 24.8%. These GHG emission reductions refer to the year 2010 compared with the emission levels in 1990. For an overview on the changes in the emissions of other countries refer to UNFCCC, 2012 (http://unfccc.int/resource/docs/2012/sbi/eng/31.pdf). GHG emissions are calculated excluding emissions/removals from land use, land-use change and forestry. When including them, the overall picture remains similar in the sense that Italy still shows reduction performances that are worse than other European countries.

[16]Whose average reduction in 2010 compared with 2012 was equal to 15.4%.

Figure 2.1: Regional distribution of air emissions (weighted by regional value added at 2005)



gest the need to perform analysis at regional level.

Furthermore, the economic literature on sectoral emission patterns and "delinking" with income growth, provides support for the need for a sector-based analysis since strong sectoral patterns have emerged (Marin and Mazzanti, 2013; Marin et al., 2012; Mazzanti et al., 2008; Mazzanti and Zoboli, 2009).

This literature highlights that the degree of technological development is "highly differentiated by sector and geographical entity" (Mazzanti et al., 2008: 296) [17].

Final confirmation of the appropriateness of this focus lies in the consideration that heterogeneities are also expected in the way regions and sectors respond to environmental pressures since those differences outlined in the social capital endowments (see e.g. Helliwell and Putnam, 1995) may engender different sector-regional innovative reactions.

2.4 Data, Methodology and Variables

2.4.1 Description of data

A limited amount of studies has exploited air emission data at sectoral and regional level of disaggregation. Most of these studies draw upon a rich and unique dataset, which is only available at the Nuts II level -to our knowledge- for Italian Regions: the regional NAMEA[18], developed by the Italian Statistical Office (ISTAT). Among them, Mazzanti and Montini (2010) have focused on the drivers of emission efficiency, adopting structural decomposition analysis to disentangle the determinants of changes in the emission efficiency of selected pollutants in Lazio (an Italian region). Costantini et al. (2013a) have focused on the economic drivers behind the geographical distribution of environmental performance for all the Italian regions. Sansoni et al. (2010) have provided a methodological and conceptual framework on the use of a regional NAMEA for international comparisons.

[17]In the Italian service sectors, the previous literature on the Environmental Kuznets Curve (EKC) outlined the existence of an inverted N-shape relationship between environmental pressure and income per capita (Marin and Mazzanti, 2013; Mazzanti et al., 2008). Unlike the service sectors, Italian manufacturing industry shows strong intra-branches heterogeneities with ceramics, paper, food and fuel manufacturing facing the worst environmental performance dynamics (Marin and Mazzanti, 2013). Furthermore, an "N shaped" or "U shaped" EKC mostly depends on the emission considered in the manufacturing sectors (Mazzanti et al., 2008).These considerations on the Italian sector and regional heterogeneities were behind our decision to ground our empirical analysis on a sector-region level of analysis.

[18]A description of the NAMEA dataset can be found in the next section.

In line with this empirical literature, we employ the Italian regional NAMEA to investigate the impact of environmental performance on the generation of green technologies.

For the empirical analysis, we merged the regional NAMEA with different data sources concerning the economic and technological performance of Italian Regions. We started exploiting patent applications, drawn from the PATSTAT database [19], to build the proxy for knowledge generation in the domain of green technologies[20]. It should be stressed that the main limitation associated with patent data in measuring technological innovation, i.e. that of measuring inventions instead of innovations, is in our case less relevant, since we are willing to understand the effect of air emission on the generation on green knowledge, irrespective of whether these inventions then enter the market or not. Such dataset covers patent applications of firms over 20 Italian Regions and all sectors (NACE Rev. 1.1, at 2-character alphabetical codes, as in Table 2.10).

After extracting patent applications generated by Italian inventors, we assigned these patents to each Italian Region, on the basis of the inventor's address, and to each sector, on the basis of firms' data. In particular, the sectoral assignment required a merge with firm data, which were drawn from the Bureau van Dijk Orbis dataset, and merged with patents on the basis of the OECD HAN correspondence tables. Over the considered time-span, the matching between ORBIS and PATSTAT through the OECD-HAN dataset allowed approximately 37% of Italian patents to be assigned to sectors[21].

Patents were then defined as being *environmental* on the basis of the

[19] PATSTAT Version: April 2011.

[20] The limits of patent statistics as indicators of technological activities are well known. The main drawbacks can be summarized in their sector-specificity, the existence of non-patentable innovations and the fact that they are not the only protecting tool.

Moreover, the propensity to patent tends to vary over time according to the cost of patenting, and it is more likely to feature large firms (Pavitt, 1985; Griliches, 1990). Nevertheless, previous studies highlighted the usefulness of patents as measures of production of new knowledge. Such studies show that patents represent very reliable proxies for knowledge and innovation, as compared with analyses drawing upon surveys directly investigating the dynamics of process and product innovation (Acs et al., 2002). In addition to the debate on patents as an output rather than an input of innovation activities, empirical analyses showed that patents and R&D are dominated by a contemporaneous relationship, providing further support for the use of patents as a good proxy of technological activities (Hall et al., 1986).

[21] We also considered alternative ways to assign patents to industrial sectors such as the application of the correspondence table implemented by Schmoch et al. (2003). However, the latter is undesirably exclusively focused on manufacturing sectors. Moreover, the correspondence is therein based on a statistical exercise while the use of the ORBIS dataset allows an official classification to be obtained.

World Intellectual Property Organization "WIPO IPC green inventory", an International Patent Classification that identifies patents related to the so-called "Environmentally Sound Technologies" and scatters them into their technology fields (Table2.12), with the caveat that it is not the only possible classification of green technologies and, as with other available classifications, it presents some drawbacks (Costantini et al., 2013b)[22].

The hybrid environmental-economic accounting matrix based on NAMEA applied to Italian NUTS II Regions has been used to assign the level of air emissions at a sectoral level to each Region[23].The Italian NAMEA has indeed the great advantage of allowing a coherent assignment of environmental pressure to economic branches. Ten greenhouse gases and air pollutants and three aggregated emissions by environmental impact are available in this dataset[24].

To avoid overlap between variables, we found it more appropriate to ground our analysis on aggregated emissions by environmental impacts, i.e. Greenhouse Gases (GHG), Acidifying Gases (AC) and Ozone Tropo-

[22]Although interesting, it is out of the scope of the current work to systematically test for the differences that may arise from the choice of classification. We selected the WIPO IPC green inventory since it is currently a wide and well established classification of green technologies. The OECD has indeed also developed the OECD Indicator of Environmental Technologies (OECD, 2011), based on the International Patent Classification (IPC), which features seven environmental areas, i.e. (a) general environmental management, (b) energy generation from renewable and non-fossil sources, (c) combustion technologies with mitigation potential, (d) technologies specific to climate change mitigation, (e) technologies with potential or indirect contribution to emission mitigation, (f) emission abatement and fuel efficiency in transportation, and (g) energy efficiency in buildings and lighting. At the same time, the European Patent Office (EPO) is working on completing its own system of classification (ECLA) to assign each patent a green tag, depending on the environmental aim of each patent. So far, EPO allows tagging technologies for adaptation or mitigation to climate change (Y02), in terms of buildings (Y02B), energy (Y02E), transportation (Y02T) and capture, storage sequestration or disposal of GHG (Y02C). More recently, Costantini et al. (2013b) have pointed to the shortcomings of classification methods based on efforts to collect IPCs potentially related to green technologies in one place. Focusing on the biofuels sector, they show that the WIPO Green Inventory is likely to overestimate the number of patents to be assigned due to the fact that IPCs are not specifically designed to identify this narrow and very specific domain. Clinical analysis based on keyword search and validations from experts are likely to yield finer grained classifications. Nonetheless, due to the wide scope of our analysis which encompasses many kinds of green technologies, we will rely on the WIPO Green Inventory.

[23]For a detailed description of the NAMEA tables, see ISTAT (2009) and Tudini and Vetrella (2012).

[24]The following pollutants are available in the dataset but have not been included in our analysis: carbon dioxide (CO_2), nitrous oxide (N2O), methane (CH4), nitrogen oxides (NO_x), sulphur oxides (SO_x), ammonia (NH3), non-methane volatile organic compounds (NMVOC), carbon moNO_xide (CO) and lead (Pb).

spheric precursors (OZ) [25] and on Particulate matter (PM10)[26].

Input-Output (Supply and Use) tables provided by ISTAT have consequently been used to build indexes of relatedness among sectors which have been adopted to generate related emissions variables, by weighting direct emissions through a weighting matrix built according to the methodology described in the next section. Unfortunately, a panel for the regionalized NAMEA is not yet available since only observations for the year 2005 have been developed (while at national level, a wide panel for Italy already exists).

Consequently, the analysis we are implementing will be a cross-sectional one since the core environmental variables are only available as a cross-section [27]. Despite this limitation, the regional NAMEA has the considerable advantage of being, to our knowledge, the only NAMEA at EU level now available at the Nuts II level. NAMEA and patent data were then merged with regional sectoral economic accounts, regional environmental expenditures and regional data on exporting activities provided by ISTAT. Lastly, regional energy consumption at sectoral level were accounted for through the deployment of TERNA data [28] to test for the robustness of our estimation results. Our sample consists of 24 NACE Rev 1.1 sectors in 20 Regions, which amounts to a pool of 480 potential observations, reduced due to some missing variables to a sample of 456 for our estimations[29].

[25]GHG, ACID and OZ are built in the NAMEA tables according to a methodology requiring the conversion of the pollutants responsible for each phenomenon in "equivalent tons". In the case of GHG, the conversion is based on their "Global Warming Potential" (GWP), i.e. the potential of global warming associated with each emission when compared with CO_2. To compute GHG equivalent emissions, CO_2, CH4 and N20 (in tons) are multiplied by their coefficients, 1 (CO_2) ; 310 (N20) and 21 (CH4) respectively.

To aggregate emissions responsible for the acidifying process (ACID), the "Potential Acid Equivalent" (PAE) of each emission measured in tons has been computed and is based on the following coefficients: 0.22 (NO_x); 0.31 (SO_x) and 0.059 (NH3). Ozone precursor emissions (OZ) take into consideration "tons of potential tropospheric ozone generation", and are computed through the following coefficients multiplied by the related emission: 0.014 (CH4); 1.22 (NO_x); 1 (NMVOC) and 0.11 (CO).

[26]PM10 has been included although it is not an aggregation of other emissions, since on the one hand, it was not included in GHG or in ACID or OZ and, on the other, it is strictly connected to production.

[27]We thank two anonymous referees for suggesting a cross-section analysis rather than a panel one which was our first choice.

[28]The company TERNA S.p.A. annually publishes "Statistical Data on Electricity in Italy" in which it collects data on the principal aspects of the national electricity sector, among which we extracted data on energy consumption by Sector and Region.

[29]Sector P (Activities of households) is not covered by NAMEA data and Sector B (Fishing) presents some missing data for six nuts2 Regions :ITC1; ITC2; ITC4; ITI2; ITF5 and ITH1-ITH2 (Trentino Alto Adige).

2.4.2 Methodology

Drawing on the literature highlighted in Section 2, we have hypothesized that, besides the traditional exogenous inducement from policy regulation, the generation of green technologies may be the outcome of an endogenous inducement mechanism. Regional polluting agents in each sector are likely to demand technologies enabling the improvement of their environmental performance so as to attract new customers, meet the preferences of sustainable customers, improve their reputation and increase their market value. At the aggregate level, this calls for investigating the extent to which in each sector-region the generation of green technologies is triggered by the environmental performance of vertically related sectors.

We also control for the impact of environmental performance within the same sector.

The literature dealing with empirical analysis of regional innovation performance is mostly based on the implementation of the so-called knowledge production (KPF) approach. The knowledge production function is one of the pillars of the applied economics of innovation (Griliches 1979, 1990, 1992; Romer, 1990; Link and Siegel, 2007) and it has been widely applied in a variety of contexts including firms, regions, industries and countries[30].

In order to investigate the impact of pollutant emissions on the regional generation of green technologies across different sectors, we therefore propose an extended knowledge generation function in which the number of green technologies (GT) is the dependent variable.

The discrete nature and non-negative nature of the dependent variable suggests the adoption of estimation techniques for count data models.

Out of these models, the equality between conditional variance and conditional mean in the distribution of the dependent variable was violated, suggesting the need for a Negative Binomial class of models instead of a Poisson.

Analysis of the determinants of the generation of GTs in our case poses an additional problem which is due to the excess sector-region

[30] In this approach, innovations, usually measured by proxies such as R&D expenses, patents and innovation counts enter the production function either directly, next to capital and labour, or indirectly, through a two-step procedure in a model that estimates its effects on the general efficiency of the same production function. In this context, the KPF is indeed what Griliches (1979) used to label "extended production function" (Krafft and Quatraro, 2011). In order to mark the difference with this approach, we will follow Antonelli and Colombelli (2013) and use the expression "knowledge generation function" which studies the direct relations between inputs that make generation of knowledge as an output possible.

combination for which we observe no GTs. This leads to a situation in which we observe an "excess of zeros" in the dependent variable, and investigation is needed to establish whether the observed zeros are due to the overall absence of patenting activity or to a specific lack of green patents in sector-region nonetheless featuring some degree of technological activity. For this specificity, we find the zero-inflated negative binomial (ZINB) model is more appropriate to fit our data since it allows empirical frameworks to be modelled in which the excess of zeros in the dependent variable is generated by a different process than count values.

This model simultaneously runs two equations: a binary logistical equation to model the zeros in the dependent variable and a proper count data estimation (negative binomial or Poisson) to model the count data dependent variable. In our specification, the LOGIT equation allows us to discriminate between the zeros due to Regions and sectors generating some patents, but no green patents, and those due to Regions that are not creating any kind of knowledge, green or otherwise. In other words, we based our inflation equation (LOGIT part of the model) on a variable (patid) that captures the count of the overall patents (irrespective of whether these patents were Environmental Technologies or not) in each region-sector combination.

The Voung test confirmed the appropriateness of our choice, as reported in the estimation results tables.

To test our hypothesis, the following basic model is specified:

$$GT_{ij} = \alpha + \beta_1 EM_{ij} + \beta_2 (W_{j,l\neq j} * EM_{i,l\neq j}) + \beta_3 PURD_i + \beta_4 POL_i + \beta_5 VA_{ij} + \beta_6 DENSITY_i + \beta_7 EXPORT\_UE_i + \beta_8 DIRTY_i + \sum_{i=1}^{n} \rho_i + \epsilon_{ij} \quad (2.1)$$

where i = 1, ..., 20 indicates the Region j =1, ..., α to β_7 24 stands for the Sector and the coefficients to be estimated. The error term is decomposed so as to account for region (ρ_i), fixed effects. The region (ρ_i), fixed effect is accounted for with the inclusion of 4 locational dichotomous variables: $NORTHEAST$, $NORTHWEST$, $SOUTH$ and $CENTER$ (benchmark). In a second step (2.2), we add a variable to the model to account for the presence of metropolitan areas in the Region ($METRO$):

$$GT_{ij} = \alpha + \beta_1 EM_{ij} + \beta_2 (W_{j,l\neq j} * EM_{i,l\neq j}) + \beta_3 PURD_i + \beta_4 POL_i + \beta_5 VA_{ij} + \beta_6 DENSITY_i + \beta_7 EXPORT\_UE_i + \beta_8 DIRTY_i + \beta_9 METRO_i + \sum_{i=1}^{n} \rho_i + \epsilon_{ij} \quad (2.2)$$

The variables included in Equation (2.1) to (2.2) are described in the following section.

2.4.3 Variables

The dependent variable, green technologies (GT), is measured by the count of patent applications in 'Environmentally Sound' technology fields in the years 2005, 2006 and 2007.

The explanatory variables are all lagged to previous year to overcome endogeneity problems that may arise. The key variables to assess our hypotheses are the environmental ones which consist of a first group of direct emission efficiency (EM_{ij}) and of a second one of related emission efficiency ($W_{j,l\neq j} * EM_{i,l\neq j}$). EM_{ij} measures the emission efficiency of the Region i and Sector j in terms of the value added of i and j. It is built according to the following specification:

$$EM_{ij} = log\left(\frac{EMISSIONS_{ij2005}}{VA_{ij2005}}\right) \tag{2.3}$$

EMISSIONS is a vector of four emission variables (GHG, AC, PM10 and OZ as in Table 2.1), each of them available at the regional and sectoral level for the year 2005 from the ISTAT regionalized NAMEA dataset.

It is worth stressing that previous contributes have used emission intensity measures to account for the stringency of regulation when the absence of specific data on regulation required the use of an approximation (e.g. Fredrikkson and Vollebergh, 2009; Costantini and Crespi, 2008). Fredrikkson and Vollebergh (2009), more precisely, constructed the dependent variable $ENERGYINTENSITY$ as the physical energy units per unit of value added, with the aim of measuring the effects of environmental as well as energy policies. Costantini and Crespi (2008) instead, adopted the level of CO_2 emissions per unit of GDP to measure environmental stringency of the importing and exporting countries. Such an indicator however, due to the way it is built, i.e. as a ratio between environmental pressure and economic performance of the Region and Sector, can also capture some structural sector features (e.g. Cainelli, Mazzanti, Zoboli, 2010).

Similarly, ($W_{j,l\neq j} * EM_{i,l\neq j}$). EM_{ij} measures the emission efficiency of the vertically related sectors and follows the following specification:

$$W_{j,l\neq j} * EM_{ij} = log\left(\frac{\sum W_{j,l\neq j} * EMISSIONS_{i,l\neq j,2005}}{VA_{ij2005}}\right) \tag{2.4}$$

In this case, EMISSIONS are weighted according to the sectoral relatedness, by using a weighting matrix which gives higher values to the emissions generated by strongly related sectors.

The matrix of sectoral relatedness has been built according to a methodology that draws upon the exploitation of input-output data (Essletzbichler, 2013; Fan and Lang, 2000; Feser, 2003).We used, as anticipated, the Italian Input Output "Supply" and "Use", which contain the flows and value of commodities produced by each industry and the flows and value of commodities consumed by each industry respectively, and constructed a matrix for the input-output relatedness between industries that follows this formulation:

$$W_{jl} = \frac{1}{2}\left(\frac{F_{jl}}{\sum_{j=1}^{n} F_{jl}} + \frac{F_{lj}}{\sum_{l=1}^{m} F_{lj}}\right) \tag{2.5}$$

whereF_{jl} and F_{lj} measure the flows between industry l and j, and have been built by multiplying the matrix of the share of one unit of the commodity c produced by industry l by the value of c consumed by industry j and vice versa.

To control for the role of economic and technology characteristics in the generation of GTs, we included the real value added (VA), the share of public R&D ($PURD$) over the total R&D and the effect of export oriented activities ($EXPORT\_UE$) in the regression, all taken at average values 2003-2005 and log-transformed [31].

To avoid a possible bias arising from the omission of policy variables, the ISTAT data have been used to build the variable POL, given by the natural logarithm of the ratio between average regional expenditure for environmental protection (only capital expenditure) in 2004-2005 of Region i and VA in 2004-2005 [32] (as in Costantini and Crespi, 2008). To interpret the industry effect better, we included a dichotomous variable, $DIRTY$, equal to 1 for the most polluting sectors and zero otherwise in the model (see Table 2.1 for details). Lastly, we controlled for the density of the Region, $DENSITY$, measured as the ratio between the

[31]In a way, export also accounts for the possible role that foreign countries regulations exert on local production, in the case of foreign environmental standards over imported goods, either for consumption or intermediate goods.

As a robustness check, we also tested an alternative variable which refers to all exporting activities without restrictions on the European market. Results have proved to be robust and are available upon request.

[32]We thank an anonymous referee for suggesting that we should build this variable on capital expenditure only instead of using total expenditure, which also includes current expenditure such as those for wages.

As a robustness check we alternatively constructed this variable by using the total regional expenditure for environmental protection and also the total regional expenditure on environmental R&D (separately). Results remained unaltered and are available upon request.

Population and the Area.

In equation (2.2) we added a dichotomous variable to our model, $METRO$, taking value 1 for those Regions in which a metropolitan area is present [33] since the literature on agglomeration economies suggests that this is where knowledge capabilities are highly concentrated [34].

Table 2.1 provides a synthesis of the definition of the variables used in the analysis.

The descriptive statistics of the variables are provided in Table 2.2. It is worth stressing that the statistics concerning the dependent variable highlight a strongly over-dispersed distribution in which the variance is far higher than the mean, suggesting the appropriateness of a Negative Binomial class of models.

Table 2.3 shows the sectoral distribution of green technologies. In Italy, over the observed period, the bulk of the GT generation is clustered in the manufacturing sector, as could be expected. In particular, about 41% of the GTs are produced in the sector dealing with the manufacturing of equipment. This suggests that much of them are embodied in intermediate capital goods. The real estate sector also deserves to be mentioned since therein it produces about 15% of the observed green patents.

In Table 2.3we also report the sectoral distribution of air emissions related to the sectoral value added. The worst environmental impact for GHG comes from the electricity, gas and water supply sector which is also responsible for high levels of OZ emissions. This is the reason why in the robustness checks we excluded this sector from the regression to test for the stability of our results. Fishing sector and the manufacturing of non-metallic mineral products are responsible for the highest amount of relative pollution of OZ, while the Agriculture sector shows the worst relative performance for AC emissions and also relative bad performance in terms of PM10. Intuitively, the transport sector is also responsible for high values, and if we look at the absolute value of equivalent tons (instead of the relative ones), it is the worst performing sector in terms of OZ and presents high values on all the other pollutants. Lastly, in Table

[33] In particular, we considered those developed around the 4 cities of Milan, Rome, Turin and Neaples metropolitan areas. When applying a less restrictive definition of metropolitan area that also includes Palermo and Florence, results remained unaltered and are available upon request.

[34] We also tested whether the use of more accurate measurement of knowledge capabilities than the *METRO* variable would have made a difference.

We tested in particular for the role of knowledge variety, knowledge coherence and knowledge diversity (following the methodology proposed by Quatraro, 2010). Since these results did not provide better insights but just confirmed the robustness of our already existing ones, for the sake of parsimony, we have omitted these variables from the analysis.

Table 2.1: Variables description

Variable	Description	Source	Year
GT	Cumulative count of green technologies in Region i and Sector j in the years 2005 to 2007	PATSTAT	2005-2007
AC	Emission intensity of Acidifying Gases (mainly NO_x, SO_x and NH3), given by the natural logarithm of the ratio between AC and the real value added of Region i, Sector j	ISTAT	2005
DENSITY	Given by the ratio of mean population in the Region i on the area of i in 2003-2005	ISTAT	2003-2005
DIRTY	Dummy equal to one for the most polluting sectors. In the NACE Revision 1.1 respectively: A, DF, DG, DI, E, I.		2005
ENERGY	Natural Logarithm of the ratio between mean Energy Consumption of Sector j in 2003-2005 and its mean value added in 2003-2005	TERNA	2003-2005
EXPORT_UE	Natural Logarithm of the ratio between average Export (within European Union) 2003-2005 and mean value added 2003-2005.	ISTAT	2003-2005
GHG	Emission intensity of Greenhouse Gases (mainly CO_2, CH4 and N2O), given by the natural logarithm of the ratio between GHG real value added of Region i, Sector j	ISTAT	2005
METRO	Dummy equal to one for Regions to which belong one of the following metropolitan areas: Milan, Rome, Turin, Neaples		
NORTHWEST; EAST CENTER SOUTH	Location dummy variables for NorthernEastern, NorthernWestern, Central and Southern Regions.		
OZ	Emission intensity of Tropospheric ozone precursors (mainly caused by NO_x, COVNM, CO, CH4) given by the natural logarithm of the ratio between OZ real value added of Region i, Sector j	ISTAT	2005
PM10	Emission intensity of PM10 (Particulates< 10Âţm), given by the natural logarithm of the ratio between GHG and the lagged real value added of Region i, Sector j, in t-1	ISTAT	2005
POL	Natural Logarithm of the ratio between average expenditure for environmental protection (only capital expenditure) in 2004-2005 of Region i and the mean value added of Region i in 2004-2005.	ISTAT	2004-2005
PURD	Given by the natural logarithm of the ratio between real mean Public R&D and mean Total R&D in 2003-2005	ISTAT	2003-2005
VA	Natural Logarithm of the mean real value added of Region i, Sector j 2003-2005	ISTAT	2003-2005
W*AC	Emission intensity of AC in 2005 from vertically integrated sectors	ISTAT	2005
W*ENERGY	Mean Energy Consumption of vertically integrated sectors on mean value edded in 2003-2005	TERNA	2003-2005
W*GHG	Emission intensity of GHG in 2005 from vertically integrated sectors	ISTAT	2005
W*OZ	Emission intensity of OZ in 2005 from vertically integrated sectors	ISTAT	2005
W*PM10	Emission intensity of PM10 in 2005 from vertically integrated sectors	ISTAT	2005

Table 2.2: Variables descriptive statistics

VAR	N	mean	sd	min	Max	skewness	kurtosis
GT	454	1.5	7.566	0	130	12.17	190.79
GHG	454	0.479	0.619	0.012	3.3	2.037	7.268
W*GHG	454	0.778	0.818	0.043	4.276	1.83	6.289
PM10	454	0.206	0.353	0.002	2.804	2.812	13.262
W*PM10	454	0.382	0.51	0.02	3.473	2.81	13.16
OZ	454	1.26	0.996	0.036	5.821	1.058	4.283
W*OZ	454	1.621	1.119	0.268	6.239	1.343	4.819
AC	454	0.091	0.197	0.001	1.489	3.484	16.84
W*AC	454	0.184	0.318	0.005	2.474	3.969	23.86
VA	454	6.639	1.783	-1.563	10.819	-0.739	3.917
PURD	454	-1.981	0.552	-3.135	-0.674	0.281	3.506
DENSITY	454	-1.912	0.636	-3.283	-0.857	-0.29	2.372
DIRTY	454	0.22	0.415	0	1	1.35	2.822
POL	454	0.091	0.091	0.011	0.311	1.196	3.152
EXPORT_UE	454	4.433	0.812	1.839	5.249	-1.482	5.674
NORTHWEST	454	0.196	0.397	0	1	1.531	3.345
NORTHEAST	454	0.2	0.401	0	1	1.497	3.24
SOUTH	454	0.352	0.478	0	1	0.618	1.382
CENTER	454	0.403	0.491	0	1	0.395	1.156
METRO	454	0.198	0.399	0	1	1.514	3.292
ENERGY	400	0.097	1.016	0	20.099	19.189	377.969
W*ENERGY	400	0.118	1.364	0	27.081	19.409	384.021

Table 2.3: Sectoral distribution of green technologies and emissions (on value added)

Sector (Nace Rev 1.1)	GHG	OZ	AC	PM10	GT	Freq(GT)
A	1.643	7.391	0.883	1.538	4	1%
B	1.361	25.88	0.396	1.951	3	0%
C	0.465	2.09	0.03	0.115	37	5%
DA	0.487	2.698	0.023	0.062	0	0%
DB	0.477	0.924	0.021	0.048	9	1%
DC	0.18	7.194	0.009	0.026	2	0%
DD, DH, DN	0.201	3.25	0.011	0.032	56	8%
DE	0.522	1.992	0.009	0.026	1	0%
DF, DG	3.067	9.699	0.317	0.264	62	9%
DI	4.039	11.119	0.315	1.475	5	1%
DJ	0.611	3.613	0.039	0.509	29	4%
DK, DL, DM	0.145	0.954	0.007	0.017	282	41%
E	6.157	6.591	0.25	0.223	21	3%
F	0.064	1.408	0.007	0.08	12	2%
G	0.14	1.064	0.014	0.064	18	3%
H	0.072	0.39	0.006	0.023	0	0%
I	0.453	4.055	0.085	0.257	8	1%
J	0.019	0.109	0.002	0.007	17	2%
K	0.031	0.201	0.003	0.014	102	15%
L	0.045	0.473	0.006	0.028	3	0%
M	0.018	0.059	0.001	0.003	0	0%
N	0.047	0.125	0.002	0.006	0	0%
O	0.773	1.927	0.032	0.046	10	1%
P	missing	missing	missing	missing	0	0%

2.4 we show the Spearman Rank correlation coefficients which account for extreme values in the considered variables.

As is clear from this table 2.4, emission intensity variables are highly correlated. Their joint inclusion in the regressions is therefore likely to engender biased estimations. For this reason, we will carry out separate estimations for each of the considered emissions. In the next section, we present and discuss the results of the econometric estimations.

2.5 Econometric results

Table 2.5 reports the results for the zero inflated negative binomial regressions of the equation (2.1), which includes total patents in the inflation part of the model. In this table we report the baseline model. As far as the control variables are concerned, only value added and R&D are statistically significant and feature a positive coefficient. The key variables of this study are however those concerning sectoral environmental performance at the regional level.

The main hypothesis underlying our empirical investigation is that environmental performance may trigger the generation of environmental technologies, working as an endogenous inducement factor. We also stress that inducement mechanisms are likely to work through the derived demand of downstream polluting firms for green technologies produced in upstream vertically related sectors. It is worth recalling that the relatedness matrix we have used to weight the impact of emissions of sectors lâĽăj on sector j is based on the input-output matrix. In other words, we measure the effects on sector j of the emissions produced by technically related sectors. Technical proximity therefore allows the effects of environmental performance of related sectors to be appreciated.

The first column in Table 2.5 reports the results concerning greenhouse gas (GHG) emissions. While the direct emissions are not significant, the emissions generated by vertically related sectors show a positive and significant coefficient. This provides initial support to the hypothesis that inducement mechanisms work thorough the transmission of incentives along the value chain. The evidence that the environmental performance of vertically related firms positively impacts the generation of green knowledge represents an aggregate result which is compatible with a microeconomic framework in which firms are increasingly aware of their environmental responsibility or at least of the economic benefits that may derive from their movements towards greener production. This holds either when those benefits come for the reason outlined in the literature on the CSR or when they are the consequence of a proactive response to future stringent regulations. Polluting firms therefore choose

Table 2.4: Spearman rank correlation coefficient

		1	2	3	4	5	6	7	8	9	10	11
1	GT	1										
2	GHG	-0.0282	1									
3	PM10	-0.0988*	0.6944*	1								
4	OZ	-0.0534	0.843*	0.7287*	1							
5	AC	-0.0706	0.9094*	0.8583*	0.8192*	1						
6	ENERGY	-0.2871*	0.4379*	0.257*	0.4359*	0.3461*	1					
7	VA	0.3095*	-0.4117*	-0.2493*	-0.424*	-0.3236*	-0.995*	1				
8	PURD	-0.1272*	0.0561	0.0646	0.0625	0.0619	0.1957*	-0.1965*	1			
9	DENSITY	0.2508*	-0.0907	-0.0948	-0.0459	-0.0963	-0.5366*	0.5398*	-0.1798*	1		
10	POL	-0.3007*	0.0704	0.1208*	0.0911	0.1208*	0.4456*	-0.4471*	0.3189*	-0.609*	1	
11	EXPORT_UE	0.2602*	-0.0005	-0.0819	-0.0828	-0.0524	-0.2216*	0.2214*	-0.5155*	-0.0541	-0.4496*	1

Table 2.5: Estimation results

	(I)	(II)	(III)	(IV)
GHG	-0.5715			
	(0.3841)			
W*GHG	1.1484***			
	(0.4087)			
PM10		-1.8422***		
		(0.6615)		
W*PM10		1.4823*		
		(0.813)		
OZ			-0.6823**	
			(0.334)	
W*OZ			1.1372***	
			(0.395)	
AC				-2.1572*
				(1.2424)
W*AC				2.8542**
				(1.4255)
VA	0.6525***	0.4763**	0.6804***	0.5391***
	(0.1907)	(0.1928)	(0.2441)	(0.183)
PURD	0.6547*	0.6978*	0.6061	0.7217*
	(0.3898)	(0.3951)	(0.3818)	(0.4037)
DENSITY	-0.0812	0.3114	-0.106	0.178
	(0.5976)	(0.5952)	(0.6182)	(0.6153)
DIRTY	0.123	0.0658	0.1067	0.0367
	(0.4672)	(0.3414)	(0.4179)	(0.384)
POL	-3.6634	-2.2849	-3.6687	-3.2615
	(4.1181)	(4.2125)	(4.1062)	(4.4774)
EXPORT_UE	0.5729	0.6247	0.548	0.5551
	(0.453)	(0.4526)	(0.447)	(0.456)
NORTHWEST	0.8026	0.5623	0.8366	0.6773
	(0.534)	(0.5478)	(0.5278)	(0.5593)
NORTHEAST	-0.1791	-0.3045	-0.0918	-0.313
	(0.4487)	(0.447)	(0.4454)	(0.4524)
SOUTH	-0.7283	-0.717	-0.8506	-0.6439
	(0.6338)	(0.6522)	(0.6344)	(0.6378)
Cons	-5.3711**	-3.1241	-5.9275**	-3.5039
	(2.3147)	(2.1622)	(2.8804)	(2.1403)
Inflate patid	-0.1138***	-0.1132***	-0.1087***	-0.1134***
	(0.0438)	(0.0409)	(0.0384)	(0.0422)
N	454	454	454	454
Log-Likelihood	-359.376	-359.162	-359.069	-360.887
Pr>LR	0	0	0	0
Likelihood-ratio test α=0 (Chi^2)	530.38	510.41	523.63	539.74
Pr>Chi^2	0	0	0	0
Vuong Test (z)	4.73	4.93	4.47	5.03
Pr> z	0	0	0	0
Mc Fadden's R^2	0.205	0.205	0.205	0.201
AIC	748.7513	748.3243	748.1389	751.7745
BIC	810.5228	810.0957	809.9104	813.5459

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

to commit resources to feed their demand for green technologies. In the second column we show the coefficients of the PM10 emissions. Here too, emissions generated in vertically related sectors exert a positive and significant impact on the generation of green technologies. Conversely, the coefficient on direct emissions is negative and significant, suggesting the existence of a negative correlation between bad environmental performance and being a producer of green technologies. The results presented in column (3) concerning the Tropospheric Ozone precursors (OZ) and in column (4) for acidifying gases (AC) are in line with the previous ones. The coefficient of emission intensities from related sectors is positive and significant whereas the one for direct emissions is negative and significant.

Overall,the patterns that emerge from these empirical results suggest the existence of complementarity between direct and related effects of sectoral emission intensities. The positive sign of the emission intensities of vertically related sectors supports the hypothesis of an endogeneous inducement channelled by the downstream firms' derived demand for green technologies produced in upstream sectors. The interpretation of such a pattern is compatible with a CSR framework in which firms try to improve their environmental performance by searching for green technologies in the markets for intermediate goods. On the contrary, firms producing and supplying green technologies are more likely to be characterized on average by better environmental performance so that the sign of direct emission intensities is actually negative and, in most cases, significant.

2.5.1 Robustness checks

Several robustness checks have been implemented to support the econometric results we presented above.

First of all, in Table 2.6 we include a dichotomous variable, $METRO$, to account for the presence of metropolitan areas in the sampled regions. In Table 2.7 we control for the role of energy consumption of each region-sector combination, both in terms of direct (ENERGY) and related (W*ENERGY) [35] consumption. The results are very consistent with the estimates presented in the previous section. Emissions from vertically related sectors are all featured by positive and significant coef-

[35]We thank an anonymous referee for suggesting this further check. Data are extracted from the TERNA database. ENERGY is constructed as the ratio between average energy consumption in 2003-2005 and the average value added in 2003-2005 for each Region-Sector combination. W*ENERGY applies the weighting matrix described in Equation (5) to ENERGY. Since not all the sectors are covered by the TERNA database, the number of observations is reduced to 400.

Table 2.6: Estimation results full specified model

	(I)	(II)	(III)	(IV)
GHG	-0.6016			
	(0.3792)			
W*GHG	1.2563***			
	(0.407)			
PM10		-2.0648***		
		(0.6667)		
W*PM10		1.7543**		
		(0.8023)		
OZ			-0.8263**	
			(0.3327)	
W*OZ			1.3378***	
			(0.3986)	
AC				-2.3252*
				(1.2269)
W*AC				3.0559**
				(1.396)
METRO	-0.6075	-0.68	-0.8019*	-0.484
	(0.4294)	(0.4269)	(0.4293)	(0.4255)
VA	0.7315***	0.5649***	0.7967***	0.5880***
	(0.1946)	(0.1939)	(0.2468)	(0.1825)
PURD	0.7164*	0.7735*	0.6663*	0.7712*
	(0.3904)	(0.3948)	(0.3811)	(0.4037)
DENSITY	0.1633	0.5727	0.1848	0.3887
	(0.5967)	(0.5806)	(0.6045)	(0.6142)
DIRTY	0.258	0.2095	0.342	0.1454
	(0.4741)	(0.3451)	(0.4235)	(0.3906)
POL	-2.0263	-0.4677	-1.539	-1.9045
	(4.2152)	(4.2716)	(4.1957)	(4.546)
EXPORT_UE	0.7255	0.7932*	0.7477	0.6741
	(0.4714)	(0.4691)	(0.4676)	(0.4719)
NORTHWEST	0.8417	0.572	0.8822	0.6914
	(0.5457)	(0.5623)	(0.5402)	(0.5715)
NORTHEAST	-0.5462	-0.7555	-0.5683	-0.6338
	(0.5297)	(0.5468)	(0.5288)	(0.5469)
SOUTH	-0.9681	-1.0408	-1.2133*	-0.8585
	(0.6572)	(0.6879)	(0.6694)	(0.6684)
Cons	-5.9593**	-3.7215*	-6.9295**	-3.7802*
	(2.3484)	(2.1584)	(2.9147)	(2.1293)
Inflate patid	-0.1069***	-0.1070***	-0.1012***	-0.1089***
	(0.0352)	(0.0336)	(0.0291)	(0.0367)
N	454	454	454	454
Log-Likelihood	-358.389	-357.911	-357.363	-360.244
Pr>LR	0	0	0	0
Likelihood-ratio test α=0 (Chi^2)	521.31	489	507.92	530.32
Pr>Chi^2	0	0	0	0
Vuong Test (z)	4.75	4.99	4.51	5.04
Pr> z	0	0	0	0
Mc Fadden's R^2	0.207	0.208	0.209	0.203
AIC	748.7779	747.821	746.7252	752.4885
BIC	814.6675	813.7106	812.6147	818.378

Standard errors in parentheses * p< 0.10, ** p< 0.05, *** p< 0.01

ficients, supporting the hypothesis of an inducement mechanism moderated by the derived demand of polluting downstream firms and all direct emission intensities but GHG emissions are featured by negative and significant coefficients.

Secondly, we tested the robustness of the results on the related emissions by adopting a different specification of the fully specified weighting matrix used in Table 2.5 and shown in Equation (2.5). We worked on the consideration that this matrix can be thought of as a proxy for technical proximity amongst sectors. Accordingly, a cutoff value can be identified that discriminates close from far sectors. The choice of this threshold is necessarily arbitrary and we grounded our choice on the distribution of the weights in the matrix. Table 2.8 reports the results of the estimations obtained by using the value of W_{ij} at the 75th percentile as cutoff.

Columns (1)-(4) show the results for the baseline estimations, whereas in columns (5)-(8) we control for energy consumption. As is clear from the table, results are well in line with those described so far of positive and significant coefficients for the emission intensities of vertically related and negative and significant coefficients for all the direct emission intensities, but GHG. While the inducement mechanisms are channeled by the vertical transmission through the value chain, the sectors responsible for the generation of green technologies are confirmed to be characterized by virtuous environmental performance. We then found it appropriate to group the emission variables into two factors, resulting from principal component analysis. The first factor represents the direct emissions while the second factor refers to the emission intensities of vertically related sectors.

The first three columns in Table 2.9report the results of the estimation yield by using the fully specified relatedness matrix whereas columns (4) and (5) show the results obtained by adopting the cutoff value Wlj at the 75th percentile. This evidence is consistent with the results of previous estimations and confirms that, even when emission intensities are grouped together in a single factor, those of vertically related sectors feature a positive and significant coefficient whereas the relationship between the production of green technologies and environmental performance is negative and significant. Our results are confirmed when the Energy sector is excluded from the analysis and also once we controlled for the regional share of manufacturing firms, either in terms of employees or in terms of value added[36]. Lastly, we provide in Table reftab:apdueuno the results obtained by running standard Poisson and Negative Binomial estimations, which are well in line with the zero-inflated models presented in Table 2.9.

[36]These results are not reported here but are available upon request.

Table 2.7: Estimation results accounting for energy consumption

	(I)	(II)	(III)	(IV)
GHG	-0.6721*			
	(0.3964)			
W*GHG	1.3581***			
	(0.4545)			
PM10		-1.8818***		
		(0.6748)		
W*PM10		1.9819**		
		(1.0017)		
OZ			-0.7282**	
			(0.3519)	
W*OZ			1.2293***	
			(0.419)	
AC				-2.2769*
				(1.2752)
W*AC				4.2012**
				(1.8355)
ENERGY	-4.7427	2.2641	-5.3562	-5.398
	(36.0608)	(31.7458)	(29.0462)	(46.8024)
W*ENERGY	-0.6266	-7.9814	0.9905	-2.8441
	(26.9952)	(24.1452)	(22.6012)	(33.6626)
VA	0.5910***	0.4636**	0.6206***	0.4949***
	(0.1925)	(0.189)	(0.2399)	(0.1761)
PURD	0.6626*	0.7798*	0.6088	0.8263*
	(0.3947)	(0.4042)	(0.3862)	(0.4226)
DENSITY	-0.0242	0.2154	-0.0517	0.1185
	(0.5862)	(0.5861)	(0.6112)	(0.5961)
DIRTY	0.0544	-0.0455	0.0285	-0.1316
	(0.4682)	(0.3464)	(0.4368)	(0.386)
POL	-3.278	-2.2149	-3.2237	-3.81
	(4.115)	(4.1616)	(4.1098)	(4.4197)
EXPORT_UE	0.7006	0.7143	0.6326	0.722
	(0.4681)	(0.4606)	(0.4559)	(0.4822)
NORTHWEST	0.8061	0.6609	0.8456	0.7821
	(0.5331)	(0.5496)	(0.5314)	(0.562)
NORTHEAST	-0.1683	-0.2814	-0.0857	-0.2789
	(0.4471)	(0.4458)	(0.4459)	(0.4512)
SOUTH	-0.8463	-0.835	-0.9495	-0.7463
	(0.6337)	(0.6593)	(0.639)	(0.6345)
Cons	-5.3964**	-3.485	-5.7812**	-3.8392*
	(2.2935)	(2.1598)	(2.841)	(2.122)
Inflate patid	-0.0970***	-0.1011***	-0.0962***	-0.0959***
	(0.0315)	(0.0346)	(0.031)	(0.0316)
N	400	400	400	400
Log-Likelihood	-348.747	-348.578	-349.072	-349.944
Pr>LR	0	0	0	0
Likelihood-ratio test α=0 (Chi^2)	518.71	493.19	513.38	527.09
Pr>Chi^2	0	0	0	0
Vuong Test (z)	4.4	4.6	4.28	4.69
Pr> z	0	0	0	0
Mc Fadden's R^2	0.201	0.202	0.201	0.199
AIC	731.494	731.1565	732.1431	733.8871
BIC	799.3489	799.0114	799.998	801.742

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 2.8: Estimation results with matrix cutoff at 75th percentile

	(I)	(II)	(III)	(IV)	(V)	(VI)	(VII)	(VIII)
GHG	-0.562				-0.6680*			
	(0.3806)				(0.3862)			
W*GHG	1.1276***				1.3603***			
	(0.3951)				(0.4462)			
PM10		-2.1162***				-2.1455***		
		(0.6637)				(0.687)		
W*PM10		2.6448***				3.0951***		
		(0.9782)				(1.1448)		
OZ			-0.7417**				-0.7981**	
			(0.3217)				(0.3311)	
W*OZ			1.2613***				1.3859***	
			(0.3447)				(0.3662)	
AC				-2.4729*				-2.6568**
				(1.2737)				(1.3056)
W*AC				3.7941**				5.3625***
				(1.5944)				(1.9587)
ENERGY					3.1483	-15.9464	-4.186	-4.5206
					(87.8513)	(85.308)	(66.9215)	(91.7332)
W*ENERGY					-7.8736	11.274	0.3342	0.6328
					(96.654)	(92.3098)	(73.3982)	(100.2348)
VA	0.5521***	0.5162***	0.6315***	0.4973***	0.4851***	0.4627***	0.5626***	0.4549***
	(0.1627)	(0.1615)	(0.2051)	(0.1497)	(0.1675)	(0.164)	(0.203)	(0.1547)
PURD	0.6474*	0.7126*	0.5709	0.7290*	0.6367	0.7481*	0.5611	0.7689*
	(0.392)	(0.3805)	(0.372)	(0.3922)	(0.391)	(0.3876)	(0.3737)	(0.3929)
DENSITY	-0.0733	0.1067	-0.1507	0.1228	0.0139	0.1075	-0.0592	0.1268
	(0.6003)	(0.5683)	(0.5805)	(0.5891)	(0.5776)	(0.5579)	(0.5722)	(0.5661)
DIRTY	0.0886	0.2655	0.1811	0.1867	0.0167	0.1868	0.0995	0.0899
	(0.4628)	(0.345)	(0.4033)	(0.3896)	(0.4584)	(0.344)	(0.408)	(0.3861)
POL	-4.1789	-3.5561	-4.342	-3.7009	-4.0075	-3.2392	-3.9679	-4.4989
	(4.1917)	(4.1625)	(3.9919)	(4.3806)	(4.1469)	(4.133)	(3.9889)	(4.3907)
EXPORT_UE	0.5266	0.6428	0.5566	0.5928	0.6345	0.7407	0.653	0.7277
	(0.4531)	(0.4445)	(0.4399)	(0.4532)	(0.4597)	(0.4573)	(0.4471)	(0.4675)
NORTHW	0.9605*	0.7044	0.9065*	0.814	0.9566*	0.7633	0.8976*	0.8813
	(0.552)	(0.5339)	(0.5171)	(0.5578)	(0.5382)	(0.5338)	(0.517)	(0.5459)
NORTHE	-0.0558	-0.1789	-0.0217	-0.1911	-0.0322	-0.15	-0.0147	-0.1313
	(0.454)	(0.4412)	(0.4364)	(0.4523)	(0.4494)	(0.4417)	(0.4346)	(0.4482)
SOUTH	-0.6736	-0.8284	-0.9763	-0.7211	-0.7967	-0.9267	-1.1057*	-0.8266
	(0.6365)	(0.6343)	(0.6206)	(0.6279)	(0.6296)	(0.6355)	(0.6228)	(0.6183)
Cons	-4.2643**	-3.9366*	-5.5531**	-3.4690*	-4.1172**	-3.9246*	-5.3490**	-3.6926*
	(2.0516)	(2.0349)	(2.4937)	(1.9655)	(2.0226)	(2.0323)	(2.4469)	(1.9749)
Inflate patid	-0.1159**	-0.1076***	-0.1010***	-0.1083***	-0.0963***	-0.0937***	-0.0880***	-0.0888***
	(0.0493)	(0.0382)	(0.0321)	(0.0385)	(0.032)	(0.0307)	(0.026)	(0.0276)
N	454	454	454	454	400	400	400	400
Log-Lik.	-358.806	-356.874	-356.315	-359.698	-347.949	-346.58	-345.942	-348.614
Pr>LR	0	0	0	0	0	0	0	0
Lik.-ratio t	526.4	486.58	508.05	532.59	511.34	481.76	497.71	518.31
Pr>Chi^2	0	0	0	0	0	0	0	0
Vuong Test (z)	4.79	5.01	4.56	4.99	4.45	4.73	4.39	4.69
Pr> z	0	0	0	0	0	0	0	0
McFadden's R^2	0.206	0.21	0.211	0.204	0.203	0.206	0.208	0.202
AIC	747.6124	743.7481	742.6296	749.3961	729.8975	727.1605	725.8846	731.228
BIC	809.3839	805.5196	804.401	811.1676	797.7524	795.0154	793.7395	799.0829

Standard errors in parentheses * $p< 0.10$, ** $p< 0.05$, *** $p< 0.01$

The weighting matrix for Related Emissions (W*GHG, W*AC; W*PM10; W*OZ) has been built with a cutoff at the 75th perc.

The weighting matrix for Related Energy (W*ENERGY) has been built with a cutoff at the 75th percentile

Table 2.9: Estimation results with principal component analysis

	(I)	(II)	(III)	(IV)	(V)
F1_DIRECT	-0.3802**	-0.4273**	-0.4012**	-0.3898**	-0.4069**
	(0.1679)	(0.1679)	(0.1743)	(0.1645)	(0.1664)
F2_RELATED	0.6234**	0.7083***	0.7820***	0.6431***	0.7841***
	(0.2446)	(0.2438)	(0.2892)	(0.2119)	(0.2402)
ENERGY			-11.175		-15.5135
			(46.2253)		(76.7143)
W*ENERGY			2.9506		11.9643
			(33.6447)		(82.6422)
VA	0.5857***	0.6746***	0.5454***	0.5401***	0.4915***
	(0.2076)	(0.209)	(0.2035)	(0.1736)	(0.1753)
PURD	0.6254	0.6838*	0.6851*	0.6202	0.6364*
	(0.3894)	(0.3883)	(0.4)	(0.3807)	(0.3812)
DENSITY	0.0527	0.3223	0.0326	-0.0172	0.0273
	(0.601)	(0.5897)	(0.5889)	(0.5799)	(0.5629)
DIRTY	0.3293	0.5253	0.2077	0.3993	0.2899
	(0.4379)	(0.446)	(0.4468)	(0.4314)	(0.4303)
POL	-3.1558	-1.2427	-2.8519	-3.9019	-3.8408
	(4.2167)	(4.3004)	(4.2006)	(4.1719)	(4.1403)
EXPORT_UE	0.541	0.7058	0.6731	0.5493	0.6628
	(0.4435)	(0.4596)	(0.4627)	(0.4401)	(0.4503)
NORTHWEST	0.6914	0.7148	0.7578	0.834	0.8609
	(0.539)	(0.5517)	(0.5411)	(0.5371)	(0.529)
NORTHEAST	-0.2259	-0.6621	-0.1959	-0.1042	-0.0676
	(0.4423)	(0.5308)	(0.4414)	(0.4412)	(0.4383)
SOUTH	-0.7888	-1.1009	-0.9013	-0.8409	-0.9653
	(0.6379)	(0.6698)	(0.6386)	(0.6257)	(0.6201)
METRO		-0.6906			
		(0.4211)			
Cons	-3.9349*	-4.5023**	-4.0007*	-3.8529*	-3.7731*
	(2.1405)	(2.1513)	(2.1029)	(1.9759)	(1.9516)
Inflate patid	-0.1109***	-0.1042***	-0.0953***	-0.1065***	-0.0896***
	(0.0405)	(0.032)	(0.031)	(0.038)	(0.0278)
N	454	454	400	454	400
Log-Likelihood	-358.869	-357.546	-348.19	-357.195	-346.398
Pr>LR	0	0	0	0	0
Likelihood-ratio test α=0 (Chi^2)	508.03	491.65	501.1	499.74	492.56
Pr>Chi^2	0	0	0	0	0
Vuong Test (z)	4.8	4.85	4.47	4.84	4.55
Pr> z	0	0	0	0	0
Mc Fadden's R^2	0.206	0.209	0.203	0.209	0.207
AIC	747.7379	747.0929	730.3808	744.39	726.7964
BIC	809.5094	812.9825	798.2357	806.1614	794.6513

Standard errors in parentheses * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Different Weighting Matrixes W* adopted:
cutoff at the 75th perc. in col (IV) and (V) and no cutoff in col.(I) to (III)
W*ENERGY uses a cutoff at the 75th perc in col.(V) and no cutoff in col.(IV)
F1_DIRECT is the linear combination of the $\neq$ classes of EM yield by applying pca
F2_ Rel is the linear combination of the $\neq$ classes of EM from vertically related sectors (pca)

2.6 Conclusions

The investigation of the determinants of the introduction of environmental innovations has gained momentum in recent years due to the important role that has been attributed to green technologies as a means of coping with economic crisis and simultaneously restoring the competitiveness of countries. In this debate, attention has been largely focused on the shaping role of constraining environmental regulatory frameworks as a mechanism for inducing the generation of green technologies.

The contribution of this paper to this stream of analysis is twofold. First, we propose a complementary framework to the standard inducement argument in climate change that acknowledges that some endogenous mechanism are at stake in the presence of a weak exogenous policy framework. We focused on Italian regions because they have been described as a context characterized by a substantial lack of stringent regulation in terms of environmental policy. Moreover, the evolution of the industrial structure in Italy has been marked by a large prevalence of small and medium sized firms characterized by thick vertical linkages in which user-producer linkages have often been the source of innovation generated in upstream sectors and adopted by downstream firms (Antonelli and Barbiellini Amidei, 2011).

We then qualify the mechanisms through which inducement mechanisms may be working, stressing that polluting firms pushed to adopt green technologies in their production processes may not possess the necessary competences to generate them. The dynamics by which an inducement on polluting firms displays its effects passes through the user-producer relationships, i.e. those established between polluting firms operating downstream and those firms generating green technologies operating upstream. These vertical linkages along the value chain are confirmed as being important in this endogenous inducement framework: increases in the derived demand engendered by the inducing factor trigger the production of green technologies by supplier firms. The underlying explanation is that regional polluting agents, when not exogenously pushed by an environmental policy, choose or are induced to commit resources to technologies enabling the improvement of environmental performance, as an effect of the two main co-occurring mechanisms of an increased social and environmental responsibility, and an opportunistic pre-emptive reaction to future regulations. This translates into an increase of the derived demand which triggers the production of GTs in vertically related sectors.

These results are obtained by applying zero-inflated negative binomial techniques and confirm an interesting pattern of relationships between environmental performance and the generation of GTs. We could indeed discriminate between direct and related effects by implementing a relatedness matrix across sectors based on input-output matrices and find evidence of complementarity between direct and related effects. The generation of GTs appears to be stimulated by vertically related sectors, providing support for the idea that user-producers interactions are shaping the ultimate effects of the inducement mechanisms on the generation of new technologies. Direct sectoral emission intensities, on the other hand, appear to be negatively related to the generation of GTs, suggesting that the sectors producing environment-friendly technologies on average feature virtuous environmental performance.

It is fair to note that our results do not imply by any means that a regulatory framework is not important. They rather suggest that stringent regulation is not the only force behind the choice to commit resources to the production of GTs and that the other way round an inducement mechanism may also be depicted in a policy weak context. Analysis of the endogenous inducement of green technologies leads to some policy measures insights which should complement the regulatory framework set. The importance of firms' awareness of the social and environmental impact of their actions calls for the implementation of entrepreneurship policies devoted to developing an entrepreneurial culture that attributes increasing importance to the environmental performance of firms. Entrepreneurs' awareness of the economic importance of their environmental performance may lead them to commit resources to R&D spending targeted at the generation of green technologies and identify new business opportunities to be exploited by spinoffs or startups.

Entrepreneurship policies could therefore benefit when traditional measures dealing with competition, the protection of property rights and the regulation of product and factor markets are complemented by adding measures to shape the entrepreneurial culture (Audretsch et al., 2007).

Our results call for further analyses at micro-level, to investigate the extent to which firms are stimulated to adopt GTs by the prospective gains in terms of reputation, and hence increase sales, or stock market value. Another future strand of possible research is to focus on the effect of environmental performance on the adoption - instead of the generation - of green technologies, by using for instance survey data [37]. Furthermore,

[37] We could not use survey data, such as the Italian Community Innovation Survey data, to assign the level of adopted green technologies to each Region since Italian data dissemination rules do not provide researchers with information on the Region of firm respondents. On the other hand, Italy is the only European country to have developed a NAMEA dataset at the regional level. This future line of research is not feasible as long as either other countries implement a regional NAMEA or the Italian Statistical Office releases innovation output data with regional information.

a possible extension could be to attribute a role not only to direct environmental performance and to inter-sectoral relatedness, as we have done, but also to regional geographical proximity since the existence of technological and environmental spillovers has been depicted in the literature (Costantini et al. 2013a). Lastly, in future research it might be worth assessing the relationship between regulatory frameworks and environmental performance, treating environmental performance no longer as an explanatory variable, but, on the contrary, as a dependent variable.

Appendix

Table 2.10: Estimation results Poisson and Negative Binomial

	(I)	(II)	(III)	(IV)	(V)	(VI)	(VII)	(VIII)
GHG	-0.09				-0.4616			
	(0.3287)				(0.4436)			
W*GHG	1.3491***				1.6826***			
	(0.3875)				(0.4437)			
PM10		-1.8214**				-1.7559**		
		(0.7247)				(0.7824)		
W*PM10		1.5883***				2.0148**		
		(0.5323)				(0.7944)		
OZ			0.0239				-0.3251	
			(0.2759)				(0.3525)	
W*OZ			1.3616***				1.7994***	
			(0.4485)				(0.4265)	
AC				-2.2413**				-2.6652*
				(1.1378)				(1.4938)
W*AC				1.3490*				2.7192**
				(0.7757)				(1.325)
VA	0.9994***	0.7663***	1.2643***	0.6523***	0.9751***	0.7123***	1.3124***	0.6403***
	(0.1995)	(0.1975)	(0.2369)	(0.1986)	(0.217)	(0.2216)	(0.271)	(0.2044)
PURD	0.6126	0.569	0.6798	0.54	1.0785***	1.1375***	1.0687***	1.1044***
	(0.4063)	(0.3632)	(0.4351)	(0.3566)	(0.4093)	(0.4133)	(0.4024)	(0.4215)
DENSITY	-0.2881	-0.029	-0.6787	0.12	0.5135	1.0725	0.0058	1.1604
	(0.7474)	(0.705)	(0.8114)	(0.7227)	(0.7019)	(0.6964)	(0.7447)	(0.7126)
DIRTY	-0.3705	0.1268	-0.5882	0.0625	0.2257	0.4581	-0.1094	0.4812
	(0.5095)	(0.4377)	(0.4724)	(0.4635)	(0.5591)	(0.4649)	(0.5094)	(0.5117)
POL	-5.8767	-6.6079	-6.6268	-6.5536	-0.4526	1.8802	-1.5947	1.6881
	(6.0241)	(5.8091)	(6.2293)	(5.6637)	(4.4439)	(4.4524)	(4.4801)	(4.7039)
EXPORT_UE	0.5192	0.5415	0.3889	0.5614	1.4046**	1.4321**	1.3082**	1.4142**
	(0.5525)	(0.5386)	(0.5441)	(0.5295)	(0.5754)	(0.5583)	(0.5769)	(0.5661)
NORTHWEST	1.4031*	1.3655*	1.6638**	1.3152**	1.1363**	0.9487*	1.2696**	0.9599*
	(0.7667)	(0.6969)	(0.8432)	(0.6663)	(0.5475)	(0.5633)	(0.5418)	(0.5795)
NORTHEAST	0.3398	0.3292	0.5237	0.2871	-0.1681	-0.2499	-0.1578	-0.2834
	(0.6413)	(0.6218)	(0.662)	(0.6077)	(0.5431)	(0.5398)	(0.548)	(0.5477)
SOUTH	-0.9719	-0.8717	-0.9729	-0.856	-1.0881*	-1.1215*	-1.1919**	-1.0170*
	(0.6479)	(0.5778)	(0.7022)	(0.5644)	(0.5806)	(0.5832)	(0.5821)	(0.5809)
Cons	-9.6938***	-7.1787**	-12.7023***	-6.0527**	-11.5838***	-8.2176***	-15.6544***	-7.4037***
	(3.0106)	(2.9686)	(3.3939)	(2.8701)	(2.6016)	(2.4526)	(3.2125)	(2.3673)
lnalpha								
Cons					1.9639***	1.9932***	1.9344***	2.0239***
					(0.1536)	(0.1545)	(0.1542)	(0.1545)
N	454	454	454	454	454	454	454	454
Log-Likelihood	-1072.175	-1080.726	-1050.894	-1105.112	-402.429	-405.393	-400.564	-407.06
Pr>LR	0	0	0	0	0	0	0	0
Likelihood-ratio test $\alpha=0$ (Chi^2)	-	-	-	-	1339.49	1350.67	1300.66	1396.11
Pr>Chi^2	-	-	-	-	0	0	0	0
Mc Fadden's R^2	0.422	0.418	0.434	0.404	0.11	0.104	0.114	0.1
AIC	2168.3509	2185.4519	2125.7887	2234.2246	830.8572	836.7855	827.1286	840.119
BIC	2217.768	2234.8691	2175.2059	2283.6418	884.3924	890.3208	880.6638	893.6543

Standard errors in parentheses * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
Results in column (I) to (IV) applied a Poisson regression estimation
Results in column (V) to (VIII) applied a Negative Binomial regression estimation

Table 2.11: Sectoral classification

Sector NACE REV 1.1	Description
A	Agriculture, hunting and forestry
B	Fishing
C	Mining and quarrying
DA	Manufacture of food products, beverages and tobacco
DB	Manufacture of textiles and textile products
DC	Manufacture of leather and leather products
DD, DH, DN	Manufacture of wood and wood products; Manufacture of rubber and plastic products Other manufacture
DE	Manufacture of pulp, paper and paper products publishing and printing
DF, DG	Manufacture of coke, refined petroleum products and nuclear fuel Manufacture of chemicals, chemical products and man-made fibres
DI	Manufacture of other non-metallic mineral products
DJ	Manufacture of basic metals and fabricated metal products
DK, DL, DM	Manufacture of machinery and equipment n.e.c. Manufacture of electrical and optical equipment Manufacture of transport equipment
E	Electricity, gas and water supply
F	Construction
G	Wholesale and retail trade repair of motor vehicles, motorcycles and personal and household goods
H	Hotels and restaurants
I	Transport, storage and communication
J	Financial intermediation
K	Real estate, renting and business activities
L	Public administration and defence; compulsory social security
M	Education
N	Health and social work
O	Other community, social and personal service activities
P	Activities of households

Table 2.12: WIPO IPC classification

TOPIC	IPC
ALTERNATIVE ENERGY PRODUCTION	
Bio-fuels	
Solid fuels	C10L 5/00
	C10L 5/40
	C10L 5/48
Torrefaction of biomass	C10B 53/02
	C10L 5/40
	C10L 9/00
Liquid fuels	C10L 1/00
	C10L 1/02
	C10L 1/14
Vegetable oils	C10L 1/02
	C10L 1/19
Biodiesel	C07C 67/00
	C07C 69/00
	C10G
	C10L 1/02
	C10L 1/19
	C11C 3/10
	C12P 7/64
Bioethanol	C10L 1/02
	C10L 1/182
	C12N 9/24
	C12P 7/06-7/14
Biogas	C02F 3/28
	C02F 11/04
	C10L 3/00
	C12M 1/107
	C12P 5/02
From genetically engineered organisms	C12N 1/13
	C12N 1/15
	C12N 1/21
	C12N 5/10
	C12N 15/00
	A01H

TOPIC	IPC
Integrated gasification combined cycle (IGCC)	C10L 3/00
	F02C 3/28
Fuelcells	H01M 4/86-4/98
	H01M 8/00-8/24
	H01M 12/00-12/08
Electrodes	H01M 4/86-4/98
Inert electrodes with catalytic activity	H01M 4/86-4/98
Non-activeparts	H01M 2/00-2/04
	H01M 8/00-8/24
Within hybridcells	H01M 12/00-12/08
Pyrolysis or gasification of biomass	
	C10B 53/00
	C10J
Harnessing energy from manmade waste	
Agricultural waste	C10L 5/00
Fuel from animal waste and crop residues	C10L 5/42
	C10L 5/44
Incinerators for field, garden or wood waste	F23G 7/00
	F23G 7/10
Gasification	C10J 3/02
	C10J 3/46
	F23B 90/00
	F23G 5/027
Chemical waste	B09B 3/00
	F23G 7/00
Industrial waste	C10L 5/48
	F23G 5/00
	F23G 7/00
Using top gas in blast furnaces to power pig-iron production	C21B 5/06
Pulp liquors	D21C 11/00
Anaerobic digestion of industrial waste	A62D 3/02
	C02F 11/04
	C02F 11/14
Industrial wood waste	F23G 7/00
	F23G 7/10
Hospital waste	B09B 3/00
	F23G 5/00
Landfill gas	B09B

TOPIC	IPC
Separation of components	B01D 53/02
	B01D 53/04
	B01D 53/047
	B01D 53/14
	B01D 53/22
	B01D 53/24
Municipal waste	C10L 5/46
	F23G 5/00
Hydro energy	
Water-power plants	E02B 9/00-9/06
Tide or wave power plants	E02B 9/08
Machines or engines for liquids	F03B
	F03C
Using wave or tide energy	F03B 13/12-13/26
Regulating, controlling or safety means of machines or engines	F03B 15/00-15/22
Propulsion of marine vessels using energy derived from water movement	B63H 19/02
	B63H 19/04
Ocean thermal energy conversion (OTEC)	F03G 7/05
Wind energy	F03D
Structural association of electric generator with mechanical driving motor	H02K 7/18
Structural aspects of wind turbines	B63B 35/00
	E04H 12/00
	F03D 11/04
Propulsion of vehicles using wind power	B60K 16/00
Electric propulsion of vehicles using wind power	B60L 8/00
Propulsion of marine vessels by wind-powered motors	B63H 13/00
Solar energy	
Photovoltaics (PV)	
Devices adapted for the conversion of radiation and energy into electrical energy	H01L 27/142
	31/00-31/078
	H01G 9/20
	H02N 6/00
Using organic materials as the active part	H01L 27/30
	51/42-51/48

TOPIC	IPC
Assemblies of a plurality of solar cells	H01L 25/00
	H01L 25/03
	H01L 25/16
	H01L 25/18
	H01L 31/042
Silicon single-crystal growth	C01B 33/02
	C23C 14/14
	C23C 16/24
	C30B 29/06
Regulating to the maximum power available from solar cells	G05F 1/67
Electric lighting devices with, or rechargeable with, solar cells	F21L 4/00
	F21S 9/03
Charging batteries	H02J 7/35
Dye-sensitised solar cells (DSSC)	H01G 9/20
	H01M 14/00
Use of solar heat	F24J 2/00-2/54
For domestic hot water systems	F24D 17/00
For space heating	F24D 3/00
	F24D 5/00
	F24D 11/00
	F24D 19/00
For swimming pools	F24J 2/42
Solar updraft towers	F03D 1/04
	F03D 9/00
	F03D 11/04
	F03G 6/00
For treatment of water, waste water or sludge	C02F 1/14
Gas turbine power plants using solar heat source	F02C 1/05
Hybrid solar thermal-PV systems	H01L 31/058
Propulsion of vehicles using solar power	B60K 16/00
Electric propulsion of vehicles using solar power	B60L 8/00
Producing mechanical power from solar energy	F03G 6/00-6/06
Roof covering aspects of energy collecting devices	E04D 13/00
	E04D 13/18
Steam generation using solar heat	F22B 1/00
	F24J 1/00

TOPIC	IPC
Refrigeration or heat pump systems using solar energy	F25B 27/00
Use of solar energy for drying materials or objects	F26B 3/00
	F26B 3/28
Solar concentrators	F24J 2/06
	G02B 7/183
Solar ponds	F24J 2/04
Geothermal energy	
Use of geothermal heat	F01K
	F24F 5/00
	F24J 3/08
	H02N 10/00
	F25B 30/06
Production of mechanical power from geothermal energy	F03G 4/00-4/06
	F03G 7/04
Other production or use of heat, not derived from combustion, e.g. natural heat	F24J 1/00
	F24J 3/00
	F24J 3/06
Heat pumps in central heating systems using heat accumulated in storage masses	F24D 11/02
Heat pumps in other domestic- or space-heating systems	F24D 15/04
Heat pumps in domestic hot-water supply systems	F24D 17/02
Air or water heaters using heat pumps	F24H 4/00
Heat pumps	F25B 30/00
Using waste heat	
To produce mechanical energy	F01K 27/00
Of combustion engines	F01K 23/06-23/10
	F01N 5/00
	F02G 5/00-5/04
	F25B 27/02
Of steam engine plants	F01K 17/00
	F01K 23/04
Of gas-turbine plants	F02C 6/18
As source of energy for refrigeration plants	F25B 27/02
For treatment of water, waste water or sewage	C02F 1/16
Recovery of waste heat in paper production	D21F 5/20
For steam generation by exploitation of the heat content of hot heat carriers	F22B 1/02

TOPIC	IPC
Recuperation of heat energy from waste incineration	F23G 5/46
Energy recovery in air conditioning	F24F 12/00
Arrangements for using waste heat from furnaces	
kilns, ovens or retorts	F27D 17/00
Regenerative heat-exchange apparatus	F28D 17/00-20/00
Of gasification plants	C10J 3/86
Devices for producing mechanical power	
from muscle energy	F03G 5/00-5/08
TRANSPORTATION	
Vehicles in general	
Hybrid vehicles, e.g HEVs	B60K 6/00
	B60K 6/20
Control systems	B60W 20/00
Gearingstherefor	F16H 3/00-3/78
	F16H 48/00-48/30
Brushless motors	H02K 29/08
Electromagnetic clutches	H02K 49/10
Regenerative braking systems	B60L 7/10-7/22
Electric propulsion with power supply from force	
of nature, e.g. sun, wind	B60L 8/00
Electric propulsion with power supply external to vehicle	B60L 9/00
With power supply from fuel cells, e.g for hydrogen vehicles	B60L 11/18
Combustion engines operating on gaseous fuels, e.g hydrogen	F02B 43/00
	F02M 21/02
	F02M 27/02
Power supply from force of nature, e.g. sun, wind	B60K 16/00
Charging stations for electric vehicles	H02J 7/00
Vehicles other than rail vehicles	
Drag reduction	
	B62D 35/00
	B62D 35/02
	B63B 1/34-1/40
Human-powered vehicle	B62K
	B62M 1/00
	B62M 3/00
	B62M 5/00
	B62M 6/00
Rail vehicles	B61

TOPIC	IPC
Drag reduction	B61D 17/02
Marine vessel propulsion	
Propulsive devices directly acted on by wind	B63H 9/00
Propulsion by wind-powered motors	B63H 13/00
Propulsion using energy derived from water movement	B63H 19/02
	B63H 19/04
Propulsion by muscle power	B63H 16/00
Propulsion derived from nuclear energy	B63H 21/18
Cosmonautic vehicles using solar energy	B64G 1/44
ENERGY CONSERVATION	
Storage of electrical energy	B60K 6/28
	B60W 10/26
	H01M 10/44-10/46
	H01G 9/155
	H02J 3/28, 7/00
	H02J 15/00
Power supply circuitry	H02J
With power saving modes	H02J 9/00
Measurement of electricity consumption	B60L 3/00
	G01R
Storage of thermal energy	C09K 5/00
	F24H 7/00
	F28D 20/00,/02
Low energy lighting	
Electroluminescent light sources	
(e.g. LEDs, OLEDs, PLEDs)	F21K 99/00
	F21L 4/02
	H01L 33/00-33/64
	H01L 51/50
	H05B 33/00
Thermal building insulation, in general	E04B 1/62
	E04B 1/74-1/80
	E04B 1/88, 1/90
Insulating building elements	E04C 1/40, 1/41
	E04C 2/284-2/296
For door or window openings	E06B 3/263
For walls	E04B 2/00
	E04F 13/08

TOPIC	IPC
For floors	E04B 5/00
	E04F 15/18
For roofs	E04B 7/00
	E04D 1/28
	E04D 3/35
	E04D 13/16
For ceilings	E04B 9/00
	E04F 13/08
Recovering mechanical energy	F03G 7/08
Chargeable mechanical accumulators in vehicles	B60K 6/10, 6/30
	B60L 11/16
WASTE MANAGEMENT	
Waste disposal	B09B
	B65F
Treatment of waste	
Disinfection or sterilisation	A61L 11/00
Treatment of hazardous or toxic waste	A62D 3/00
	A62D 101/00
Treating radioactively contaminated material decontamination arrangements therefor G21F 9/00	
Refuse separation	B03B 9/06
Reclamation of contaminated soil	B09C
Mechanical treatment of waste paper	D21B 1/08
	D21B 1/32
Consuming waste by combustion	F23G
Reuse of waste materials	
Use of rubber waste in footwear	A43B 1/12
	A43B 21/14
Manufacture of articles from waste metal particles	B22F 8/00
Production of hydraulic cements from waste materials	C04B 7/24-7/30
Use of waste materials as fillers for mortars, concrete	C04B 18/04-18/10
Production of fertilisers from waste or refuse	C05F
Recovery or working-up of waste materials	C08J 11/00-11/28
	C09K 11/01
	C11B 11/00
	C11B 13/00-13/04
	C14C 3/32
	C21B 3/04

TOPIC	IPC
	C25C 1/00
	D01F 13/00-13/04
Pollution control	
Carbon capture and storage	B01D 53/14
	B01D 53/22
	B01D 53/62
	B65G 5/00
	C01B 31/20
	E21B 41/00
	E21B 43/16
	E21F 17/16
	F25J 3/02
Air quality management	
Treatment of waste gases	B01D 53/00-53/96
Exhaust apparatus for combustion engines with means for treating exhaust	F01N 3/00-3/38
Rendering exhaust gases innocuous	B01D 53/92
	F02B 75/10
Removal of waste gases or dust in steel production	C21C 5/38
Combustion apparatus using recirculation of flue gases	C10B 21/18
	F23B 80/02
	F23C 9/00
Combustion of waste gases or NO_xious gases	F23G 7/06
Electrical control of exhaust gas treating apparatus	F01N 9/00
Separating dispersed particles from gases or vapours	B01D 45/00-51/00
	B03C 3/00
Dust removal from furnaces	C21B 7/22
	C21C 5/38
	F27B 1/18
	F27B 15/12
Use of additives in fuels or fires to reduce smoke or facilitate soot removal	C10L 10/02
	C10L 10/06
	F23J 7/00
Arrangements of devices for treating smoke or fumes from combustion apparatus	F23J 15/00
Dust-laying or dust-absorbing materials	C09K 3/22
Pollution alarms	G08B 21/12

TOPIC	IPC
Control of water pollution	
Treating waste-water or sewage	B63J 4/00
	C02F
To produce fertilisers	C05F 7/00
Materials for treating liquid pollutants	C09K 3/32
Removing pollutants from open water	B63B 35/32
	E02B 15/04
Plumbing installations for waste water	E03C 1/12
Management of sewage	C02F 1/00
	C02F 3/00
	C02 F 9/00
	E03F
Means for preventing radioactive contamination in the event of reactor leakage	G21C 13/10
AGRICULTURE / FORESTRY	
Forestry techniques	A01G 23/00
Alternative irrigation techniques	A01G 25/00
Pesticide alternatives	A01N 25/00-65/00
Soil improvement	C09K 17/00
	E02D 3/00
Organic fertilisers derived from waste	C05F
ADMINISTRATIVE, REGULATORY OR DESIGN ASPECTS	
Commuting, e.g., HOV, teleworking, etc.	G06Q
	G08G
Carbon/emissions trading, e.g pollution credits	G06Q
Static structure design	E04H 1/00
NUCLEAR POWER GENERATION	
Nuclear engineering	G21
Fusion reactors	G21B
Nuclear (fission) reactors	G21C
Nuclear power plant	G21D
Gas turbine power plants using heat source of nuclear origin	F02C 1/05

Chapter 3

Environmental innovations and profitability: how does it pay to be green? An empirical analysis on the German Innovation Survey

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Abstract

Much of the empirical literature analysing the relation between environmental innovation and competitiveness has focused on the question whether "it pays to be green". We differentiate between different types of environmental innovations, which will be disentangled in those aiming at reducing the negative externalities and those allowing for efficiency increases and cost savings. What we analyze is at first the extent to which these two typologies have impacts on firms' profitability with opposite signs, and, secondly, whether the motivations driving the adoption of those innovations make the difference in terms of economic gains. We find empirical evidence that both the typology of environmental innovation and the driver of their adoption affect the sign of the relationship between competitiveness and environmental performance. Innovations leading to a reduction in the use of energy or materials per unit of output positively affect firms' competitiveness. Contrarily, externality reducing innovations hamper firms' competitiveness. The empirical strategy is based on a sample of German firms and makes use of a merge of two waves of the Mannheim Innovation Panel in 2011 and 2009 that allow overcoming some endogeneity issues which may arise in a cross-section setting.

JEL Classification Codes: Q55, Q20, M10, K32

Keywords: Profitability, Externality Reducing Innovations, Energy and Material Efficiency Innovations, Mannheim Innovation Panel

3.1 Introduction

The broad 10-year growth strategy "Europe 2020" of the European Commission, aiming at a smart, sustainable and more inclusive economy by 2020 (EC, 2010), is depending upon improvements towards a greener production that may lead to a "decoupling" of environmental pressure and economic growth.

The generation and adoption of environmental innovations (from now on EI [2]) by firms are consequently keys to improve the sustainability of the production processes.

This holds either when innovations are integrated in the production process (Cleaner Production measures) or when innovations are add-on measures that allow to reduce the negative externalities of the production in the last stage of the production process, for example by including specific filters to reduce pollution (end-of-pipe technologies). Previous literature has highlighted the peculiar nature of EI (e.g. Horbach, 2008; Rennings, 1998, 2000) and, suggesting the need of a multidisciplinary approach (e.g. Kemp, 2010), has recently contributed to a better understanding and identification of the determinants that are beyond the generation and the adoption of EI within firms.

Whereas a consensus on the determinants of EI [3] seems to be growing,

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[2] Multiple and exhaustive definitions of EI have been provided by the literature (e.g. Kemp and Pearson 2007; Kemp, 2010; Rennings, 1998, 2000). Among them, the one we will be referring to is the following: "the production, assimilation or exploitation of a product, production process, service or management or business methods that is novel to the firm [or organization] and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives" (Kemp and Pontoglio, 2007, p. 10).

[3] The extant ecological economics literature has mainly agreed on the relevance of a cluster of EI determinants (e.g. Horbach 2008; Horbach et al., 2012) mainly $Market-pull$ (e.g. Kammerer, 2009; Rehfeld et al., 2007), $Technology-push$ (e.g. Horbach, 2008), $Firmspecificfactors$ (e.g. Horbach et al., 2012) and $Regulation$ (e.g. Brunnermeier and Cohen, 2003; Costantini and Crespi, 2008; del Rio, 2009; Ghisetti and Quatraro, 2013; Popp, 2002; Rennings and Rexhäuser, 2011; Rennings and Rammer, 2011)with a relevant role attributed to the adoption of management schemes to improve environmental performance (e.g. Theyel, 2000; Wagner et al., 2002, 2008; Ziegler and Nogareda, 2009)

The access to knowledge sources coming from outside the firms' boundaries is also found to be relevant (De Marchi, 2012; Cainelli et al., 2011; Mazzanti and Zoboli, 2005, 2009): relying on external knowledge sources is indeed positively influencing the adoption of EI and the enlargement of an EI portfolio within firms (Ghisetti et al., 2013). Furthermore, the investigation of what determines firms'attitude towards cleaning behaviors has provided evidences of an important role of social pressure, cognitive and attitudinal factors as well as of technological factors and opportunities and organizational capabilities, all of them moderated by the perceived risks and the

the economic implications of their adoption are still widely debated, to understand whether firms are missing (getting) economic opportunities in improving (not improving) their environmental performances.

We contribute to this debate on whether it pays or not to "be green" by proposing a differentiation between different typologies of EI.

Our main argument is that it depends on how to be green, i.e. the "box" of EI has to be opened to disentangle the competitiveness effect of their adoption. Some neutral or even negative profitability effects might be associated with EI that are only aiming at reducing negative production externalities, while some positive economic benefits are indeed expected when EI are cost saving and/or efficiency improving innovations.

Our corollary argument is that what drives the adoption of EI can influence the competitive outcome of the EI itself. Section II discusses the theoretical framework our research is based upon.

The empirical analysis is carried out on the Mannheim Innovation Panel dataset for the years 2011 and 2009 and will be made clear in Section III. Section IV provides a discussion of our results and highlights a set of robustness checks we implemented to reinforce our estimates. Section V concludes.

3.2 Theoretical framework

A deep research effort has been devoted to the analysis of the economic performance effects of improvements in the environmental performances at various levels of analysis, where economic performance has been conceived through short-term measures, such as profitability or even longer term measures that capture firms' competitiveness.

While still no clear answer has been provided, the research question whether it pays or not to be green has existed for a long time.

According to the natural-resource-based view [4] (NRBV) of the firm, it is expected that firms' profitability is positively influenced by the competitive advantages generated by the accounting of the natural environment

overall attitude towards the development of clean technologies (Montalvo, 2002, 2003, 2008).

[4]The NRBV somehow challenges the Resource Based View of the firm as it ignored how the interaction between an organisation and its natural environment helps explaining the competitive advantages (Hart, 1995). According to this view, and without the willingness to be exhaustive, three key strategic capabilities are at stake: pollution prevention, product stewardship, and sustainable development, each of them facing different drivers, building upon different resources and engendering heterogeneous competitive advantages (Hart and Dowell, 2011).

as this pro-active behavior favors the development of strategic resources that are engendering positive economic returns (Hart, 1995).

Ecosystem degradation and resources depletion engender a threat to firms' resources (Hart and Dowell, 2011), and as a reaction, firms can pro-actively adopt an environmental strategy (Hart, 1995), which can be read as the development of a dynamic capability [5] (Aragon-Correa and Sharma, 2003; Hart and Milstein, 2003).

To this respect, firms facing higher risks associated to climate change are those subject to greater incentives to develop green strategies (Hoffman, 2005). Moreover, the idea that it pays to be green became even more attractive when it was linked to the NRBV as "it is a theory of how an individual firm might gain a competitive advantage by going green" (Berchicchi and King, 2007: 516). The economic benefits deriving from pollution reduction are, however, usually underestimated by managers (e.g. Hart, 1995; Berchicchi and King, 2007 for a discussion) and this might lead to sub-optimal levels of environmental efforts if it is acknowledged that innovations might more than offset the cost of compliance to stringent environmental standards (Porter and van der Linde, 1995).

This underestimation can be driven by the costs associated to collecting proper information about the values and returns of different pollution reduction factors as firms can be unwilling to bear the search costs and thus can underexploit or abuse certain "greener" production techniques (King and Lenox, 2002). Waste prevention processes, for instance, have proved to be underexploited because of their not-directly-observable benefits (e.g. King and Lenox, 2002; Russo and Fouts, 1997).

Lastly, the literature on Corporate Social Responsibility (CSR) (e.g. Porter and Kramer, 2002 and 2006), which is centered on environmental responsibility (e.g. Hart, 1997; Orlitzky et al. 2011), provides insights on the potential positive gains associated to a socially responsible behaviors. According to these studies (e.g. Ambec and Lanoie, 2008; Kotler and Lee, 2003; Margolis and Walsh, 2003), irrespective of whether the adoption of cleaner technologies can be a by-product of a strategy aiming at improving firms'market evaluation, or the access to new (green) markets, or as part of a cost-reduction strategy (Ambec and Lanoie, 2008), such an adoption might still engender positive business performance effects.

Given this framework of analysis, a range of empirical studies have been devoted to test the relationship between financial and environmental performance in a firm-level analysis (e.g. Freedman and Jaggi, 1992;

[5] All in all, the concept of dynamic capability, originally developed by Teece and Pisano (1994) has been applied to the "environmental" realm. In such a framework developing and adopting environmental strategies has been interpreted as a way itself for the firm of developing dynamic capabilities (Aragon-Correa and Sharma, 2003; Hart and Milstein, 2003).

Jaggi and Freedman 1992). Those studies provided a very mixed picture on the signs of this relation and on the empirical strategies to be adopted. According to Horvthov (2010), 15% of them found a negative, 55% a positive, and 30% found no effect of environmental performances on economic performance.

In studying the profitability effects, measured as Returns on Equity (ROE), of environmental performance ratings in the pulp and paper industry, Bragdon and Marlin (1972) found support that it pays to be green. The same positive sign, but with different measures of financial performance, can also be found in Russo and Fouts (1997), adopting Returns on Assets (ROA), in Salama (2005), assessing the Corporate Financial Performance, and in King and Lenox (2001) and Dowell et al. (2000), adopting the Tobins' q index.

King and Lenox (2002) provided some further insights by showing that the positive correlation between financial and environmental performance were driven by a particular type of practice, i.e. the waste prevention methods. A confirmation that less polluting firms benefit from improved financial performances also comes from Hart and Ahuja (1996), who furthermore highlighted that Operating Performance (Returns on Sales (ROS) and ROA) was benefiting from the year after the initiation of pollution prevention strategies, while it required 2 years before financial performance (in terms of ROE) was positively affected.

To overcome the simultaneity problem that may arise in a cross section setting, i.e. that environmental and economic performance usually go hand in hand as they are jointly determined and jointly depending on the unobservable firms' management strategy, Al-Tuwaijri et al. (2004) adopted a Three Stages Least Squares estimation (following Ullmann, 1985) and still found support of a positive relationship between environmental and economic performance.

Contrarily to those evidences, in studying the effect of environmental performance on financial performances measured as ROS on a sample of US firms in a cross-section setting, Sarkis and Cordeiro (2001) and Cordeiro and Sarkis (1997) found support for short-term negative effects, which were stronger for pollution prevention strategies than for end-of-pipe measures.

A negative effect on the Return on Capital Employed (RoCE) was also found in the European context, in particular, on the European paper industry using a simultaneous structural model, but when adopting different measurements for the financial performance, such as ROE or ROS, the effect was no longer significant (Wagner et al., 2002). Similarly, a neutral effect is also detected by Freeman and Jaggi (1992).

However, Elsayed and Paton (2005) suggested that previous mixed results were driven by misspecification issues, which were due to the inability of previous contributes to properly account for unobserved firms' fixed effects. In confronting a static and a dynamic panel analysis on UK data, they found that environmental performance has only a weak impact on the financial performance as outlined by their dynamic specification, while the cross-section one suggested stronger (biased) correlations. Coherently, Telle (2006) argued the conclusion that "it pays to be green" is premature, as when applying a random effect panel model instead of a pooled OLS one, the positive economic gains of environmental performances were no longer significant.

These heterogeneous results pointed to the conclusion that the question is no longer if it does pay to be green, but rather *when* or *for whom* it pays (Telle, 2006; King and Lenox, 2001).

We argue that the question has to be better qualified in terms of the typologies of environmental innovations to be considered as what we expect is that different EI engender heterogeneous competitiveness effects in a firm-level analysis. Thus, we formulate the research question as *"How does it pay to go green?"*.

EI can indeed be decomposed into at least two typologies, Energy and Resource Efficiency Innovations (from now on $EREI$), i.e. those innovations whose effects consist in a reduction of material and energy used per unit of output, and Externality Reducing Innovations (ER from now on), i.e. those innovations aimed at reducing production externalities such as air, water, noise pollution and harmful materials.

Although both $EREI$ and ER face the "double externality problem" typical for EI, as they still produce innovation spillover and reduce negative production externalities, empirical evidences have been provided that the two typologies are inherently different, either in the drivers (e.g. $EREI$ benefit more from the use of external information sources) or in the productivity (sales over employees) or in the role of barriers to innovation, which are perceived as more intense for $EREI$ than for other EI (Rennings and Rammer, 2009).

Evidence is also found that the effects of firm' s "green" investment strategy improve firm' s productive efficiency only when the investment in cleaner production technologies is targeted at reducing (simultaneously) both the externalities and the use of raw materials (Antonietti and Marzucchi, 2013). Furthermore, firms' ability to generate profits may differ, depending on their resource bases, between those that respond to a policy compliance by introducing end-of-pipe innovations and those that redesign their production processes and services (Russo and Fouts, 1997).

The introduction of end - of - pipe technologies does not fundamentally modify production processes, thus it does not alter neither firms' resources nor capabilities.

Consequently, it is not expected to engender any positive effects on firms' competitiveness, while it can rather be just a cost burden to the firm and leading to negative outcomes.

Improved environmental performances are indeed expected to engender positive competitive gains when a change in the resource bases and capabilities follows the redesign of the production process (Russo and Fouts, 1997). As *EREI* are actually leading to a reduction in the use of physical resources, they can consequently be a source of competitive advantage and thus they are expected to exert a positive effect on firms' profitability. Investments in end-of pipe technologies are instead found to be associated with lower performance (Klassen and Whybark, 1999), thus we can expect a different sign for *ER*.

Cleff and Rennings (1999) analyzed the categories of end - of - pipe technologies versus cleaner production technologies, finding evidence that end - of - pipe technologies are more related to the motivation of compliance with environmental regulation while cleaner production technologies are more often introduced for economic reasons such as market share and cost reduction. Many cleaner production technologies may be improving energy or material efficiency, and many end-of-pipe technologies may internalize external effects, however the relation of the categories to economic theory is not as clear as in the case of *EREI* and *ER*. While the categories of *EREI* and *ER* can be explained by investment in private versus public goods, this is not as clear for cleaner production versus end-of-pipe.

Coherently our main hypothesis is that profitability effects of *EI* are heterogeneous and depend on the typology considered. *EREI* are expected to positively affect profitability, as they can lead to a "win win" situation in which the improvement of environmental performance is leading to economic gains.

Furthermore, the idiosyncratic characteristics of the resources energy and materials might lead firms to benefit of a competitive advantage when they introduce *EREI*. *ER* are instead less related to the exploitation in the production process of scares resources that may engender competitive advantages, in case are uniquely exploited and combined. Those are though not expected to lead to positive profitability gains, as no "win win" situation might be related to their adoption.

Secondly, we test whether the motivations behind firms' decisions to adopt *EREI* or *ER* may themselves impact on their profitability gains. In particular we are going to test whether *EREI* or *ER* introduced in response to a current or foreseen regulation (*EREI_REG* and

ER_REG) engender different profitability gains compared to *EREI* or *ER* introduced as a reaction to the availability of financial incentives, grants or subsidies specifically targeted at introducing *EI* (*EREI_GR* and *ER_GR*), and also compared to *EREI* or *EI* that were voluntarily introduced by firms thanks to the existence of voluntary codes or agreements for good environmental practices (*EREI_VOL* and *ER_VOL*).

As far as *EI* introduced as a response to regulation are concerned, a wide strand of research emerged to test the existence of a Porter-like mechanism in assessing the competitiveness effects of the adoption of a stringent environmental regulation. On the one side, environmental regulation has been seen as a threat to firms' competitiveness (e.g. Gollop and Roberts, 1983) or as a cause that induces firms to relocate their production in less regulated areas as the literature on the pollution haven hypothesis points out (e.g. Brunnermeier and Levinson, 2004 for a survey).

On the other side, since the seminal contribution by Porter and van der Linde (1995), a strand of literature aimed at testing the presence of a possible "win-win" solution has emerged, which may arise after the introduction of an environmental regulation [6] (Beise and Rennings, 2005).

[6]Several empirical studies provided a confirmation of this hypothesis and it is not the aim of the current work to provide an exhaustive revision of such a wide and articulated research field.

What we are willing to highlight is that, according to the Porter hypothesis, strict regulation is not necessarily damaging competitiveness, but can indeed often enhance it. A properly designed regulation may indeed trigger innovation allowing to offset, partially or fully, the cost of complying to those standards (Porter and van der Linde, 1995).

Pollution is not only a production externality that diverts the costs from the firm to the whole society, as seen in the standard approaches, but it is often also a waste of resources for the firm, for example in terms of energy-inefficient production processes. Consequently, a properly designed regulation might call firms' attention about these inefficiencies and suggest technological improvements leading firms to a Pareto improvement, coupling environmental protection with competitiveness enhancement (Ambec et al., 2013). Moreover, the introduction of a specific regulation in one industry j in a specific country i, may engender a "first mover" competitive advantage to the firms located in i and belonging to j when compared to firms belonging to countries that will be introducing such environmental constraints only in a further period (e.g. Beise and Rennings, 2005).

A confirmation of the hypothesis comes from several empirical studies, for instance, Rassier and Earnhart (2010) found that the Clean Air Act regulation has improved the ROS both in the short and in the long run in a sample of publicly owned firms in the US chemical manufacturing industry and Lanoie et al. (2008), studying the effects of the stringency of regulation and Total Factor Productivity growth in Quebec manufacturing sector, found that the effects are stronger for industries more exposed to international competition and positive in the long run while negative in the short run.

Since Porter sees resource efficiency as a part of firms total efficiency, his hypothesis would imply that mainly $EREI$ show positive effects on competitiveness, while the effects of ER depend on the degree that environmental external effects are already internalised by regulation. Mixed results have emerged in the empirical literature on the Porter hypothesis. Rexhäuser and Rammer (2013) were the first who properly distinguished between $EREI$ and ER in testing for the existence of a Porter-like mechanism and indeed found a confirmation of the Porter hypothesis only for $EREI$, which exert a positive effect on firms' profitability either when they are or are not regulation driven, while negative effects are exerted by ER [7].

What follows is our second hypothesis that profitability effects of $EREI$ and ER vary according to the motivation that was driving their adoption by firms as each of the three motivations may affect the adoption of heterogeneous innovations and this is moderating the profitability effects of the innovation itself. Regulation driven EI are mainly leading to an internalisation of negative externalities which can also be beneficial to the firm, according to the argument articulated so far and coherently with the Porter hypothesis. On the other side, financial incentives are usually provided for the introduction of innovations that are not profitable on their own, thus moderating the adoption of less profitable EI, which are in our case ER rather than $EREI$, while voluntary adopted EI are expected to lead mainly to cost saving innovations rather than to innovations which are perceived as a cost-burden to the firms.

3.3 Empirical strategy

3.3.1 Data

The empirical test of our research hypothesis makes use of the Mannheim Innovation Panel (MIP), an annual survey based on a panel sample of German firms conducted by the Centre for European Economic Research (ZEW) in Mannheim.

The 2009 wave of the MIP includes a set of questions on EI that are coherent with the European Community Innovation Survey (CIS) 2006-2008. The advantage of the MIP with respect to the CIS lies in the fact that it also surveys information on firm profitability and market structure that allows building our dependent and control variables. Furthermore, as it will be outlined below, we benefited from the opportunity to merge 2

[7] Nevertheless, the negative effect disappears for ER which are driven by current or expected regulation, while it is persistently negative for ER which are not regulation-driven.

waves of the survey in order to lag the explanatory variables with respect to the dependent one. The target population are enterprises with 5 or more employees from most economic sectors [8] and the sample is stratified by sector (56 sectors at the 2-digit level of NACE rev. 2.), size class (8 classes according to the number of employees) and region (West Germany and East Germany). The voluntary nature of the survey is the reason for a response rate that is lower than in compulsory surveys [9]. More importantly, a non-respondent test has been implemented to test the presence of a selection bias in the responses and this excluded the existence of systemic differences between respondents and non-respondents.

The operative sample used in this research consists of 1063 observations, which is equal to the 15% of the total sample surveyed in the MIP 2009. The loss of observations is due to the fact that the samples of the two waves of the MIP that we merged, i.e. the MIP 2009 and the MIP 2011, did not include the same firms, to the high attrition rate of firms, and to the non-responses to all our core variables. We were able to match only 44% of firms surveyed in the MIP 2009 with the MIP 2011. Furthermore, most of the firms surveyed in both waves did not answer all the questions asked, thus reducing the sample for which we have information on all the variables we modeled to 1063. A set of robustness checks have been performed to exclude the presence of a sample selection bias in our estimates and these will be discussed in the following sections.

3.3.2 Empirical model and variables description

Our first research hypothesis is based on the argument that it is required to differentiate between the typologies of EI, in particular $EREI$ and ER, to assess the profitability effects of those innovations will be tested by confronting the estimations of the model presented in equation (3.1) and those in equation (3.2), (3.3) and (3.4).

$$OM_i = \alpha + \beta_1 EI_i + \beta_2 MS_i + \beta_3 HHI_i + \beta_4 SIZE_i + \gamma SECT_i + \epsilon_i \tag{3.1}$$

$$OM_i = \alpha + \beta_1 EREI_i + \beta_2 ER_i + \beta_3 MS_i + \beta_4 HHI_i + \beta_5 SIZE_i + \gamma SECT_i + \epsilon_i \tag{3.2}$$

[8] Excluding farming and forestry, hotels and restaurants, public administration, health, education, and personal and cultural services. For further details on the MIP, see Janz et al. (2001) and Aschhoff et al. (2013).

[9] In 2009 the response rate was 26 percent, corresponding to more than 7.000 firms that is not an unusual response rate for voluntary mail surveys in Germany (Grimpe and Kaiser, 2010).

$$OM_i = \alpha + \beta_1 EREI_i + \beta_2 ER_i + \beta_3 MS_i + \beta_4 HHI_i + \beta_5 SIZE_i + \beta_6 RD_i + \beta_7 LPAT_i + \beta_8 PC_i + \gamma SECT_i + \epsilon_i \tag{3.3}$$

$$OM_i = \alpha + \beta_1 EREI_i + \beta_2 ER_i + \beta_3 MS_i + \beta_4 HHI_i + \beta_5 SIZE_i + \beta_6 RD_i + \beta_7 LPAT_i + \beta_8 PC_i + \beta_9 EAST_i + \gamma SECT_i + \epsilon_i \tag{3.4}$$

Our dependent variable in all the models is firms' profitability (OM).

We model firms' profitability empirically in terms of Returns on Sales by adopting as a dependent variable (OM) the estimated operating margin, meant as pre - tax profits over sales (as in Czarnitzki and Kraft, 2010 and Rexhäuser and Rammer, 2013). In order to reduce non-responses, OM data are collected through categorical values that are self-reported by firms on an interval scale that follows the distribution presented in Table 3.1. As investing in a new environmental technology is probably leading to increasing costs in the short run, while its competitive gains in possible terms may only be realised in a subsequent period (e.g. Hart and Ahuja 1996, Elsayed and Paton, 2005), we found it more appropriate to expect that the adoption of EI in 2006 - 2008 may engender profitability gains or losses after a certain time lag. For this reason, our dependent variable is extracted from a subsequent wave of the survey, the MIP 2011, while all the explanatory variables refer to the MIP 2009 wave.

The merge of these waves of the survey also allows overcoming those endogeneity problems deriving from the simultaneity between OM and the explanatory variables and the possible reverse causality issue. More precisely, this merge allows to model the estimated operating margins in 2010 (OM) on a set of explanatory variables all referred to the time lag 2006-2008 [10].

However, the choice of OM as dependent variables still brings about a set of issues that need to be discussed.

At first, the merge of two waves of the survey might engender a selection bias due to the (possible) attrition of firms with similar observable and/or unobservable characteristics within the waves as we anticipated

[10] In this way we let environmental innovations introduced in the time lag 2006-2008 to start having profitability gains from 2 to 4 years later, i.e. in 2010. An appropriate choice regarding the time lag is needed. Our choice is supported by previous findings. Hart and Ahuja (1996) found that operating performance (ROS and ROA) required one or two years to be affected by environmental performance, but the effect starts being no longer significant after the third year of lag. Financial performance (ROE) required instead a time lag of at least 2 years (Hart and Ahuja, 1996). Coherently, we need to choose a lag which is not too short (so we excluded OM measured in 2008) or too long (so we excluded OM measured in 2012). We thus find our choice of a 2 to 4 years lag more adequate than the available alternatives.

when we described the operative sample. In the section on the robustness checks this is discussed. Furthermore, the choice of using self-reported price-cost margin data instead of more objective data might itself be a limitation.

On the other side, it has to be remarked that in Germany the majority of firms were not required to publish their accounting data. Consequently, the alternative of using balance sheet data instead of the self-reported would have engendered a clear selection bias as only data for large firms, in particular stock corporations, would have been available.

On the contrary, the use of the Mannheim Innovation Panel variable, although self-reported, guarantees the coverage on a representative sample and this is, in our opinion, a valid motivation for our choice [11].

Table 3.1: Distribution operating margin 2010

OM	Freq.	Percent
< -5%	60	5.64
-5% to 2%	38	3.57
-2% to 0%	59	5.55
0% to 2%	156	14.68
2% to 4%	161	15.15
4% to 7%	216	20.32
7% to 10%	150	14.11
10% to 15%	127	11.95
>15%	96	9.03
Total	1063	100

Recalling that all the explanatory variables refer to the time lag 2006-2008, to assess the first research question, three key environmental dichotomous explanatory variables have been constructed: EI, $EREI$ and ER [12]

[11] We had to test for the possible bias that may arise because of the presence of missing values in the dependent variable. A discussion is available in the robustness checks section.

[12] The CIS 2006-2008 introduced an ad-hoc section on environmental innovation in which firms were asked to answer whether a new or significantly improved product, process, organisational method or marketing method that creates environmental benefits were introduced, independently on whether the benefits were the primary objective of the innovation or its by-product and independently on whether the innovation was new to the market or just to the firm adopting it. Firms were asked to choose among a set of typologies of environmental innovations they might have introduced.

The German CIS is wider than the harmonised one as it includes more typologies of EI a firm can choose with a set of 9 indicators for process innovations, i.e. 3

The first takes value one when at least one process innovation with high environmental benefits has been introduced out of a scale of 9 different dimensions (see Table 3.2), independently on the specific nature of the innovation, and is estimated in Equation (3.1).

From equation (3.2) to (3.4) the environmental innovation variable will be split into $EREI$ and ER in order to assess our first research question. $EREI$ takes value one when two conditions are simultaneously met: a) the firm has introduced process innovations bringing to a reduction of energy and/or material used per unit of output or to a reduction of CO_2 emissions and b) this process innovations lead to high environmental benefits[13].

Similarly, ER is equal to one when externality-reducing process innovations leading to high environmental protection have been adopted by the firm and zero otherwise. Process innovations that reduce air, soil, water and noise pollution as well as those to replace dangerous materials belong to the externality-reducing category. Coherently with previous literature (Rexhäuser and Rammer, 2013), process innovations that improve recycling possibilities are not assigned to any of the two types mainly because recycling may either be a material-saving innovation (thus $EREI$) or an externality-reducing innovation (ER), depending on whether it saves the usage of materials or water, or conversely, it improves the recyclability of wastes [14].

As in Rexhäuser and Rammer (2013), the CO_2 emission reduction dimension has been assigned to $EREI$ (and not to ER) as it is not feasible to pursue any CO_2 emission reduction without energy efficiency improvements as the major driver of CO_2 emissions comes from the energy mix

more than the harmonised CIS, and 3 for product innovations. Furthermore, the German version of the CIS allows firms to rank the environmental benefits associated to each typology of EI introduced following a 4-point Likert scale (no, small, medium, high environmental benefit). It has to be acknowledged that environmental benefits reported suffer of the limitation that they are subjective, i.e. depending on the respondent' s perception, rather than objective, i.e. based for instance on measurable objective indicators.

[13]The questionnaire asks firm to report for each environmental innovation typology introduced its contribution to environmental protection out of a low, medium, high scale.

As the interest of this analysis lies in the competitiveness effects of environmental innovations leading to effective environmental protection, the decision was to focus only on those with high effects. In a subsequent step also those with high and medium effects will be considered.

[14]To be sure that this exclusion does not engender a bias in our results we controlled whether the assignment of the recycled waste, water or materials category, first to ER and separately to $EREI$, would have changed our estimation results. We conclude that results are stable in both the cases. A table with these results is available upon request.

used (for a discussion see Cainelli and Mazzanti, 2013).

We acknowledge that CO_2 emission reduction innovations are inherently different from energy and material reduction ones. For this reason we needed to test a) whether the exclusion of these innovations from the analysis and b) whether the assignment of these innovations to the ER category would have engendered some changes in the results we provided. Results are stable in both the cases [15]. Lastly, given the nature of the research question, environmental product innovations will be excluded from this analysis [16]. See Table 3.2 for details in the distributions and composition of $EREI$ and ER and the dimensions of EI considered.

In our baseline specifications in Equation (3.1) and (3.2) we control for some variables that have been found to be correlated with our dependent variable in previous studies (e.g. Czarnitzki and Kraft, 2010).

More precisely the Herfindahl concentration index (HHI),and some firm observable heterogeneities such as size and market share ($SIZE$ and MS) taking lagged values from the previous wave of the survey to reduce endogeneity problems. As the literature on firms' profitability suggests, highly concentrated markets may pose different competitive conditions to the firms, and this might impact on firms' own profitability. More precisely, previous literature suggests that highly concentrated industries, i.e. industries in which a small number of firms account for a great number of industrial activities, should show higher profitability possibilities (Capon, Farley and Hoenig, 1990).

Furthermore, monopolistic markets may predict higher profitability. Accordingly, the Herfindahl concentration index at Sector-level 3-digit calculated by the German Monopoly Commission (HHI), as well as self-reported (in MIP) firms market share within the top-selling line of products (MS) have been included in the analysis. As a further robustness check, industry concentration measures of the 3 ($C3$) and 6 ($C6$) biggest firms calculated by the German Monopoly Commission has substituted HHI and as they showed very similar results, they are no longer included in the tables [17].

The natural logarithm of employees corrected for part time workers

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[15] A table with these results is available upon request.

[16] The competitiveness returns of new products or services reducing air, water, soil or noise pollution or energy use, or with improved recycling possibilities after use will be mainly depending on demand condition rather than on direct efficiency gains ($EREI$) or on direct environmental compliance costs (ER). Their inclusion into either $EREI$ or ER variable might thus be misleading in the interpretation of their effect on competitiveness in this specific context. Nevertheless, future research might be focused on a different research question whose more accurate focus will allow including environmental product innovations.

[17] These tables are available upon request.

Table 3.2: Key environmental variables EREI and ER in MIP 2009

Environmental Process Innovations	Share of EI with low, medium or high environmental benefits	Share of EI with high environmental benefits	Type of EI
Reduced Material per unit of output	37%	5%	EREI
Reduced energy per unit of output	44%	6%	EREI
Reduced CO_2 footprint	34%	6%	EREI
Reduced air pollution	24%	4%	ER
Reduced water pollution	24%	4%	ER
Reduced soil pollution	15%	2%	ER
Reduced noise pollution	24%	2%	ER
Replaced dangerous materials	24%	4%	ER
Recycled waste, water or materials	39%	5%	None

Source: Mannheim Innovation Panel 2009

is used to control for the size of the firm ($SIZE$).

Description and descriptive statistics of the variables are reported in Table 3.3.

We then add in Equation (3.3) and in Equation (3.4) to the baseline specification some further variables that may influence firm' heterogeneous profitability and have been suggested to us by previous literature. Given the pairwise correlation outlined in Table 3.4 we found it more appropriate not to proceed with a joint inclusion of all the control variables of the full specified model in Equation (3.4) as some potentially problematic correlations are depicted.

Coherently, in Equation (3.3) we add to previous controls two variables that capture firms' technological heterogeneities. The first, RD, is a dichotomous variable accounting for the existence of R&D activities, either internal or external. We also controlled for firms' technological heterogeneities deriving from differences in the knowledge stock through the natural logarithm of patent stock ($LPAT$), by applying the perpetual inventory method to patent applications at the European Patent Office between 1978 and 2008 and depreciating the stock of knowledge capital by a 15% yearly discount rate (Griliches and Mairesse, 1984) [18].

The expectation, coherently with previous findings, is that of a positive relationship of these variables with OM.

In Equation (3.4) we add a control for the role of being a (non-environmental) process innovator with dichotomous variable equal to one if the firm introduced (non-environmental) process innovation (PC) in the period 2006-2008 [19] and for the East Germany transition process, through a location variable ($EAST$). In all the equations 19 sector dummies are included ($SECT$) (as described in Table 3.8) to control for sectoral heterogeneities that may emerge and impact on the estimation results.

We can now move to the empirical test of the second hypothesis. Recalling that it suggests that EI induced by different determinants heterogeneously affect firms' profitability, its test is conducted by estimating the models in Equations (3.5) to (3.7).

$$\begin{aligned} OM_i = \alpha + \beta_1 EREI\_REGi + \beta_2 ER\_REG_i + \beta_3 EREI\_NOREGi \\ + \beta_4 ER\_NOREG_i + \beta_5 MIXED\_REG_i + \gamma CONTROLS_i + \epsilon_i \end{aligned} \tag{3.5}$$

[18] The presence of many non-patenting firms engenders a limit when computing the natural logarithm of the patent stock. We then substituted 0 values with 0.001, by adding 0.001 to patent stock before computing its natural logarithm

[19] As in Czarnitzki and Kraft (2010) we tried to capture the presence of cartelistic behaviors by adding an interaction variable $RD * Herfindhal$ index and the presence of collusion by an interaction variable MS* $Herfindhalindex$. As they were both found not to be significant, they are no longer included in the analysis.

Table 3.3: Variable description and descriptive statistics

variable	Description	Source	Year	N	Mean	Std Dev	Min	Max
OM	Estimated Operating Margin, i.e. profit before taxes on income as a percentage of turnover	MIP11	2010	1063	5.614	2.123	1	9
EREI	Energy, Material and CO_2 reduction process innovations with high environmental benefits	MIP09	2006-08	1063	0.106	0.308	0	1
ER	Externality reducing process innovations with high environmental benefits	MIP09	2006-08	1063	0.104	0.306	0	1
EAST	Eastern Germany Location	MIP09	2008	1063	0.332	0.471	0	1
SIZE	Natural Logarithm of employees corrected for the part time workers	MIP09	2008	1063	4.028	1.577	0.41	10.3
RD	Engagement in internal or external R&D activities	MIP09	2006-08	1063	0.485	0.5	0	1
PC	Process Innovators	MIP09	2006-08	1063	0.394	0.489	0	1
HHI	Herfindahl concentration index at 3 Digit (German Monopoly Commission GMC)	GMC	2007	1063	46.941	78.59	0.21	644
LPAT	Natural Logarithm of Patent Stock, built according to the perpetual inventory method	PatStat	1978-08	1063	-7.489	3.719	-9.21	6.1
MS	FirmÂťs market share within the top-selling line of products	MIP09	2006-08	1063	0.275	0.302	0	1
EREI_REG	EREI introduced in response to a current or future regulation, excluding overlapping assignments that are captured by MIXED_REG	MIP09	2006-08	1013	0.022	0.146	0	1
ER_REG	ER introduced in response to a current or future regulation, excluding overlapping assignments that are captured by MIXED_REG	MIP09	2006-08	1013	0.039	0.195	0	1
EREI_VOL	EREI introduced voluntarily, i.e.in response to sectoral voluntary codes or agreements for environmental good practices, excluding overlapping assignments, captured by MIXED_VOL	MIP09	2006-08	1013	0.017	0.129	0	1
ER_VOL	ER introduced voluntarily, i.e.in response to sectoral voluntary codes or agreements for environmental good practices, excluding overlapping assignments, captured by MIXED_VOL	MIP09	2006-08	1013	0.017	0.129	0	1
EREI_GR	EREI introduced in response to the availability of government grants, subsidies or other financial incentives, excluding overlapping assignments that are captured by MIXED_GR	MIP09	2006-08	1013	0.009	0.094	0	1
ER_GR	ER introduced in response to the availability of government grants, subsidies or other financial incentives, excluding overlapping assignments that are captured by MIXED_GR	MIP09	2006-08	1013	0.003	0.054	0	1
EREI_NOREG	EREI introduced but not in response to a current or future regulation	MIP09	2006-08	1013	0.055	0.229	0	1
ER_NOREG	ER introduced but not in response to a current or future regulation	MIP09	2006-08	1013	0.034	0.18	0	1
EREI_NOVOL	EREI introduced but not in response to sectoral voluntary codes or agreements for environmental good practices	MIP09	2006-08	1013	0.066	0.249	0	1
ER_NOVOL	ER introduced but not in response to sectoral voluntary codes or agreements for environmental good practices	MIP09	2006-08	1013	0.062	0.242	0	1
EREI_NOGR	EREI introduced but not response to the availability of government grants, subsidies or other financial incentives	MIP09	2006-08	1013	0.086	0.28	0	1
ER_NOGR	ER introduced but not response to the availability of government grants, subsidies or other financial incentives	MIP09	2006-08	1013	0.088	0.283	0	1
MIXED_GR	EI induced by the existence of government grants, subsidies without the possibility to disentangle EREI from ER as they were both introduced in response to this motivation	MIP09	2006-08	1013	0.014	0.117	0	1
MIXED_VOL	EI introduced voluntarily without the possibility to disentangle EREI from ER as they were both introduced in response to this motivation	MIP09	2006-08	1013	0.026	0.158	0	1
MIXED_REG	EI induced by regulation, without the possibility to disentangle EREI from ER as they were both introduced in response to this motivation	MIP09	2006-08	1013	0.032	0.175	0	1

Table 3.4: Main variables correlation matrix

		1	2	3	4	5	6	7	8	9	10
1	OM	1									
2	EREI	0.0627	1								
3	ER	0.0026	0.4411	1							
4	EAST	0.0133	-0.0164	-0.0644	1						
5	SIZE	-0.0234	0.1061	0.0713	-0.1439	1					
6	RD	0.0568	0.1291	0.1485	-0.0694	0.2357	1				
7	PC	0.0559	0.1403	0.1715	-0.0537	0.2717	0.4183	1			
8	HHI	0.0083	-0.0081	0.0156	-0.0627	0.1254	0.1338	0.106	1		
9	LPAT	0.0345	0.0672	0.0165	-0.1122	0.3601	0.3621	0.19	0.0757	1	
10	MS	0.0291	0.0195	0.0406	0.0109	-0.0667	-0.0799	-0.1228	0.0502	-0.0381	1

$$
\begin{aligned}
OM_i = \alpha + \beta_1 EREI\_VOLi + \beta_2 ER\_VOL_i + \beta_3 EREI\_VOLi \\
+\beta_4 ER\_VOL_i + \beta_5 MIXED\_VOL_i + \gamma CONTROLS_i + \epsilon_i
\end{aligned}
\tag{3.6}
$$

$$
\begin{aligned}
OM_i = \alpha + \beta_1 EREI\_GRi + \beta_2 ER\_GR_i + \beta_3 EREI\_GRi + \beta_4 ER\_GR_i \\
+\beta_5 MIXED\_GR_i + \gamma CONTROLS_i + \epsilon_i
\end{aligned}
\tag{3.7}
$$

The rationale is to include in these Equations (3.5) to (3.7) all the controls of the full specified model of the previous Equation (3.4), which are now synthetically labeled $CONTROLS$, and to modify the key environmental innovation variables. Those will be included separately to avoid multicollinearity among those environmental innovation regressors.

To test our second hypothesis, we consequently built a group of $EREI$ and ER variables that differ according to the motivation behind their adoption.

The MIP 2009 asks the firms to state whether an EI was introduced as a response to a list of determinants, among which we are interested in: a) an existing or a foreseen regulation, which allows us to create the regulation-induced variables ($EREI\_REG$ and ER_REG) and the non-regulation induced ($EREI\_NOREG$ and ER_NOREG); b) the availability of government grants, subsidies, or other financial incentives to EI, which allowed us to build our grant induced variables ($EREI\_GR$ and ER_GR) as well as the non-grant induced ones ($EREI\_NOGR$ and ER_NOGR) and c) voluntary codes or agreements for environmental good practices, through which we built our voluntary agreements variables ($EREI\_VOL$ and ER_VOL) as well as the non-voluntary agreements driven ones ($EREI\_NOVOL$ and ER_NOVOL)[20].

The survey does not allow to properly distinguish between a regulation that induced $EREI$ from one that induced ER, it only gives information on whether an EI (general) has been induced by regulation and this applies to grants and voluntary codes as well. In the case of regulation, we could not univocally assign 180 regulation-induced innovations either to $EREI$ or to ER.

In the case of voluntary codes, the number of ambiguous assignments is 152, while it is 64 in the case of grant-driven innovations. For this reason we include in each specification in equation (3.3) to (3.5) a variable for those situations in which an ambiguous assignment was depicted, i.e. in the cases in which REG, GR or VOL induced both $EREI$ and ER ($MIXED\_REG$; $MIXED\_GR$ and $MIXED\_VOL$).

[20]The sample slightly changes when moving to the extended specification in Equation (3.5) to (3.7) because of some missing values in the answers provided by respondents on the motivations for EI. The number of observations available for testing the second hypothesis is 1013 instead of 1063, as in Table 3.6.

We consequently replace those $EREI$ and ER with zero for which the assignment was ambiguous not to double count them in the estimations. The underlying rationale for such a structure is to have in each equation as complement to one only the non-introduction of any EI [21] in order to use it as the benchmark to interpret the coefficients of the dummy variables we included in the models.

Given that our dependent variable is a categorical variable with the known thresholds as outlined in Table 3.1, we can estimate it through an interval regression model, which allows us to model fixed and known cut points, which are in our case both left and right censored, and estimate the coefficients and Σ^2 via Maximum Likelihood (Wooldridge, 2002). [22]

3.4 Results, discussion and robustness checks

Estimation results of Equation (3.1) to (3.4) are provided in Table 3.5. Recalling that column (I) reports the results when the EI variable does not make any differentiation on the nature of the innovation itself, we find that in general the adoption of an EI does not play any effect on firms' profitability.

If we had stopped here, we would have concluded that a neutral relationship has been depicted between EI and profitability and that it does not pay to be green. But when we decompose EI by $EREI$ and ER, we instead find a clear confirmation of our first research hypothesis, namely that it is appropriate to differentiate between Energy and Resource-Efficient innovation and the Externality-Reducing ones as different profitability effects are expected.

More precisely, $EREI$ are exerting a positive and strongly significant

[21]For each $EREI$ and ER we can indeed have the following situations: $non-EI$ ($EREI$ or ER equal to 0), EI driven by one of the three motivations ($EREI$ or ER equal to one; motivation - REG, GR or VOL - equal to one, EI not driven ($EREI$ or ER equal to one; motivation equal to zero). Moreover for each motivation we have a mixed category we described as MIXED above. In the case of regulation, for instance, we have overall the following categories: $EREI\_REG$, $EREI\_NOREG$, ER_REG, ER_NOREG, $MIXED\_REG$; NO_EREI; NO_ER.

If we had included in the regressions only EREI_REG and ER_REG, we could have not been able to disentangle the profitability effect among a) $EREI$ or ER which were not driven by REG, b) $MIXEDEI$ driven by REG and c) $non-EI$ firms. For this reason we included in the regressions also $EREI\_NOREG$, ER_NOREG and $MIXED\_REG$, so as to keep as benchmark (complement to one) the only category of $non-EI$.

[22]We further checked the validity of our results by transforming the dependent variable in a Likert scale one, which ranges from 0 to 9 and we estimated the same models with Ordered Probit and Ordinary Least Squares. As expected results remain unaltered. Those are available upon request.

Table 3.5: Estimation results

	(I)	(II)	(III)	(IV)
EI	0.3976			
	(0.4984)			
EREI		1.8502***	1.7776***	1.7403***
		(0.6578)	(0.6591)	(0.6579)
ER		-1.1512*	-1.1915*	-1.2831*
		(0.6753)	(0.6821)	(0.6795)
SIZE	-0.0408	-0.0504	-0.1114	-0.1457
	(0.1305)	(0.1306)	(0.1383)	(0.1397)
MS	0.6053	0.6266	0.6088	0.6964
	(0.7713)	(0.7633)	(0.7627)	(0.7662)
HHI	-0.0041	-0.004	-0.0041	-0.0044
	(0.0029)	(0.0029)	(0.0029)	(0.003)
RD			0.4938	0.289
			(0.4558)	(0.4832)
LPAT			0.047	0.0469
			(0.063)	(0.0629)
EAST				-0.0468
				(0.4208)
PC				0.5902
				(0.452)
Constant	2.8375***	2.8254***	3.2666***	3.3091***
	(0.9344)	(0.9399)	(1.1847)	(1.1855)
Lnsigma				
Constant	1.8180***	1.8146***	1.8136***	1.8126***
	(0.028)	(0.0281)	(0.0281)	(0.0281)
N	1063	1063	1063	1063
MLCox-Snell R2	0.055	0.061	0.063	0.065

Standard errors in parentheses * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
19 Sector Dummies, jointly significant (Wald Test), have been included

effect on firms' profitability, while on the contrary, ER are negatively impacting firms' operating margins (column (II)). This result is robust to the subsequent inclusion of additional control variables (column (III) and (IV)).

The expectation that increased resource efficiency engenders a positive economic effect is confirmed. On the one side $EREI$ are innovations that in reducing the use of materials and energy they reduce production costs. On the other side different combinations in the use of these idiosyncratic resources can engender a competitive advantage that a firm can exploit in the market. The magnitude of the positive gain is so depending on the way these two intertwined mechanisms are at work.

ER are conversely neither associated to a cost reduction in the production nor to possible competitive advantages deriving from the exploitation of strategic resources. In general adopting an innovation is a costly process for the firm and when those innovations are ER, the costs actually overcome the benefits in a way that the profitability return of such an adoption becomes negative.

To better appreciate the results outlined above, we now exploit the information on what is the motivation behind the adoption of EI and test our second research hypothesis by estimating Equation (3.5) to (3.7). Results are reported in Table 3.6.

What emerges is that the motivation behind the adoption of an EI makes the difference in terms of profitability gains, giving a first confirmation of the validity of our second research hypothesis.

When an EI is introduced as a response to a current of future regulation ($EREI\_REG$ and ER_REG) with respect to the case in which it is not driven by regulation ($EREI\_NOREG$ and ER_NOREG), ER is still hampering firms' competitiveness, coherently with our previous results, while $EREI$ remains positive and significant. This last result is coherent with the Porter hypothesis framework of analysis, according to which regulation may help firms in seeking new production solutions that allow them to more than offset the costs of compliance and to take advantage of competitive gains that derive from that. However, to properly account for the existence of a Porter-like mechanism, a proper and well-designed regulation might be at stake, while we have no information on the quality of the regulation we are accounting for in our data [23]

As regulation typically induces firms to internalise their externalities, the interpretation of our results can be the following: when regulation works only in the direction of reducing production externalities forcing firms to engage in ER, then it can actually hamper firms' profitability. On the other side, when regulation induces firms to improve their resource

[23]Furthermore, this is out of the scope of the current paper.

efficiency, it results in productivity gains for the firms.

Moreover, *EREI* and *ER* introduced not as a response to environmental regulation do not affect firms' profitability. More interestingly and coherently with the previous result, when *EI* are introduced in response to the availability of government grants, subsidies, or other financial incentives, their effect on competitiveness are confirmed to be negative for *ER*, and no longer significant for *EREI*. This result can be interpreted by considering that a financial incentive is usually paid for innovations that are not profitable on their own.

And it is mainly paid for adopting *ER* innovation rather than *EREI*, since *EREI* may not be eligible for state aids with the same frequency. In line with this reasoning, *EREI* are proved to engender positive profitability effects only when they are not introduced as a response to a financial incentive (*EREI_NOGR* is positive and significant).

Furthermore, the negative effect of ER on profitability is higher than that reported in Table 3.5, suggesting that the negative profitability effect of ER is even stronger when those innovations are motivated by the presence of a financial incentive. The explanation might lay in the lack of an "additionality" effect of this subsidy or grant. In other terms, some firms may opportunistically substitute innovations undertaken as a response to the incentive while, at the same time, abandon any further innovation activity. This behavior might end up with stronger losses for the firm. A proper test on the grant additionality is however not possible in this context for the absence of specific data.

Unfortunately the survey from which we built the variables under investigation does not allow to have precise information on the nature of the specific grant or financial incentive that firms are actually receiving [24].

Lastly, when the driver of the adoption is the presence of voluntary codes or agreements, no effects on competitiveness are depicted. Intuitively the adoption of such voluntary codes is intertwined with organizational costs, which are not necessarily making the adoption itself

[24] We can assume that generally financial incentives or grants are paid for the adoption of innovations that firms would not otherwise introduce, but we are conscious that the whole spectrum of financial incentives and grants is heterogeneous. Grants might indeed be paid also for the development of new and cleaner technologies that would alone lead to gains also in the absence of the financial incentive, and here the expectation would be of a positive profitability effect. However, our data do not allow to differentiate the profitability effect of each and every incentive among this spectrum. We are only able to get information on whether firms received any financial incentive or not and, consequently, to interpret the net (profitability) effect of such heterogeneous policy interventions when they moderated the adoption of environmental innovations. Future research using different data might be devoted to shed light on this issue and we thank an anonymous referee for this suggestion.

Table 3.6: Estimation results EI disentangled by drivers

	(I)	(II)	(III)
EREI_REG	1.7726*		
	(1.0424)		
ER_REG	-1.8817**		
	(0.911)		
EREI_NOREG	1.3738		
	(1.0072)		
ER_NOREG	-0.7887		
	(1.4041)		
MIXED_REG	0.9503		
	(0.91)		
EREI_VOL		1.1825	
		(1.3684)	
ER_VOL		-1.8301	
		(1.4693)	
EREI_NOVOL		2.0289**	
		(0.8007)	
ER_NOVOL		-1.1232	
		(0.8536)	
MIXED_VOL		0.2572	
		(1.1979)	
EREI_GR			0.298
			(1.0669)
ER_GR			-6.7765***
			(1.7819)
EREI_NOGR			2.0365***
			(0.7451)
ER_NOGR			-1.0242
			(0.7398)
MIXED_GR			-0.4049
			(1.6742)
SIZE	-0.119	-0.1175	-0.1131
	(0.1422)	(0.1422)	(0.1419)
RD	0.2106	0.2103	0.2054
	(0.4964)	(0.4962)	(0.4966)
LPAT	0.0421	0.0464	0.0452
	(0.0636)	(0.0643)	(0.0639)
MS	1.0802	1.0674	1.0048
	(0.7899)	(0.7912)	(0.7924)
HHI	-0.0057*	-0.0058*	-0.0056*
	(0.0032)	(0.0032)	(0.0032)
EAST	-0.067	-0.0772	-0.0446
	(0.4312)	(0.4327)	(0.4314)
PC	0.6033	0.5867	0.5716
	(0.4661)	(0.4675)	(0.4651)
Constant	3.1272**	3.1468***	3.0722**
	(1.2163)	(1.2157)	(1.2092)
lnsigma			
Constant	1.8085***	1.8088***	1.8068***
	(0.0286)	(0.0286)	(0.0287)
N	1013	1013	1013
MLCox-Snell R2	0.065	0.065	0.067

Std errors in parentheses * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
19 Sector Dummies, jointly significant (Wald Test) included

profitable. On the other side, $EREI$ that are not introduced as a response to voluntary codes or agreements of conduct exert a significant and positive role on the dependent variable ($EREI\_NOVOL$ is positive and significant). Lastly, sectoral heterogeneities in the adoption of these codes of conduct have a role and might help explaining this result.

We previously built our $EREI$ and ER variables by accounting only for those innovations having a high environmental impact. If we instead include also those innovations reporting medium or high environmental benefits, then we can shed more light on the nature of the relationship between EI and profitability.

In Table 3.7 we report estimation results of Equation (3.1) and (3.2) in which we replaced respectively EI and $EREI - ER$ by adopting a more extensive category of EI, to include also those with medium environmental impact. What we find is that none of the key environmental variables is still significantly affecting firms' profitability. This suggests not only that the question whether it pays or not to be green should be better qualified as profitability effects arise not in general. More interestingly, it suggests that a minimum threshold of (green) innovativeness is required before profitability gains arise. Profitability effects might indeed arise only for firms introducing highly innovative innovations, i.e. innovation whose impact on the environment is strong, while it does not arise for the entire spectrum of EI one might consider.

Several robustness checks have been implemented to support the validity of our estimation results.

At first, we consider that firms may be reluctant in providing profit information data. Indeed, among the 6851 firms of the MIP2011, 1451 did not answer to the operating margin variable and 703 stated that it was unknown. To test for the presence of a bias that may arise from the missing values encountered in our dependent variable OM, we constructed a dichotomous variable equal to 1 when information on OM are provided and 0 otherwise and we modeled the probability of providing information on OM through a probit model and regressed it on all the explanatory variables in equation (3.2), rejecting the null hypothesis that the non-response to OM is random (as in Rexhäuser and Rammer 2013).

As the variable that is driving the non-randomness of the non-responses is $EAST$, significant in the probit model, it has been selected to construct the exclusion restriction in a two-step Heckman selection model (Heckman, 1979). The coefficient of the mills ratio in the Heckman model is not statistically significant. This suggested that a proper selection bias is not depicted in our sample data and that the estimation model we selected above was more appropriate. However, the results we presented were confirmed by this selection model, as $EREI$ and ER were both

Table 3.7: Estimation results EI with medium or high environmental benefits

	(I)	(II)
EI (med or high)	-0.16	
	(0.4212)	
EREI (med or high)		-0.0735
		(0.4687)
ER (med or high)		0.135
		(0.4851)
SIZE	-0.1314	-0.1355
	(0.1399)	(0.1412)
RD	0.3238	0.2972
	(0.4887)	(0.4868)
LPAT	0.0548	0.056
	(0.0633)	(0.0633)
MS	0.6691	0.6573
	(0.7758)	(0.7778)
HHI	-0.0045	-0.0044
	(0.0029)	(0.0029)
EAST	-0.0023	0.0088
	(0.4224)	(0.4212)
PC	0.6255	0.5813
	(0.4609)	(0.4592)
Constant	3.4456***	3.4098***
	(1.1939)	(1.1902)
Lnsigma		
Constant	1.8161***	1.8161***
	(0.028)	(0.028)
N	1063	1063
MLCox-Snell R2	0.052	0.052

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
19 Sector Dummies, jointly significant (Wald Test), have been included

reporting the expected signs and were both significant [25].

As we have anticipated, the non-response to all the variables in the sample restricted our operative sample to only 1063 observations. We then controlled that the operative sample did not systematically differ from the full sample in the mean of the main variables included into the analysis, which are reported in Table 3.9. We see that our results are robust as the dependent variable (OM) and our main explanatory variables ($EREI$, ER and EI) do not present significant differences in the means between the sample we used in the regression and the full sample (that is representative of the population)[26].

3.5 Conclusions

Whether it pays or not to be green has been a core topic of the empirical literature on environmental and economic performance over the past two decades and assessing this question contributes to evaluate whether it is possible to maintain economic growth without giving up to increasing environmental performances. With a focus on the firm level and by analyzing survey data for the German firms, we contribute to this debate by showing that the question needs to be better qualified if we want to empirically operationalise it. Our main finding is that it is indeed more appropriate to open the box of the environmental realm and separately consider the competitive gains of different typologies of EI, those reducing externalities from those increasing energy and resources efficiency. It depends on how to be green.

If we look at innovations leading to a reduction in the use of energy and resources, we can conclude that it definitely pays to be green. If we then turn to innovations aimed at reducing externalities, such as harmful materials and air, water, noise and soil pollutions, we should conclude that it does not pay to be green. Although it may be profitable in the long run due to improved environmental regulation, it does not pay off in the short run when environmental regulation has to be faced as an external restriction. Energy and Resource Efficient innovations are here confirmed to lead to potential "win win" situations, in which reducing the environmental impact of production is contextually improving firms' economic performances.

[25] These results are not reported here but are available upon request.

[26] We also recognise that some of the control variables we included (HHI, RD, $SIZE$, PC, $EAST$ and $LPAT$) are significantly different in the two samples. Although this might change the coefficients of those variables in our regression results, we do not consider it a limitation to our analysis as they were just included as control variables and we have not even commented their potentially biased coefficients.

The same conclusion does not hold for externality reducing innovations, for which the cost burden of the adoption of the innovation seems to overcome the potential gains. A threshold of green innovativeness seems to be at stake and this discriminates between profitable innovations and not profitable one. Only highly (green) innovative firms are indeed found to benefit from the adoption of $EREI$. When looking at the drivers that work behind the adoption of each typology of EI considered, we confirm that the motivation inducing their adoption significantly impacts the profitability effects of the innovations. Again, this confirms our main hypothesis of the need to better articulate the question to allow identifying specific heterogeneous patterns that we found in our data. Lastly, a Porter- like mechanism emerges as far as regulation induced $EREI$ are concerned, confirming previous results in the field (Rexhäuser and Rammer, 2013).

The current work suffers however of a set of limitations we could not solve. One of the main limitations of this analysis lies in the cross-sectional nature of the data. Although the merge of two subsequent waves of the Mannheim Innovation Panel allows to include an appropriate time lag between the dependent variable and the explanatory variables, so as to overcome endogeneity issues, it is still reasonable to assume that profitability is also depending on firms' unobserved heterogeneity, for instance, on technology level or managerial quality, that a panel analysis setting would have allowed to control for. Unfortunately, the key environmental variables were only available for the 2009 wave, thus limiting a panel exploitation of the data. The best effort was made in trying to capture the majority of elements driving to observed heterogeneity by adding a set of lagged comprehensive controls, but the room for unobserved heterogeneity is still open and it is not possible to model for it accurately in a cross section setting.

On the other side, the great advantage of this analysis lies in the use of specific survey data on the adoption of environmental innovation, which allows overcoming the limits of previous studies deriving from the need to find adequate proxies for EI.

Another (smaller) limitation lies in the specific time frame we considered. Although Germany is one of the European countries who recovered faster from the economic downturn and that it is consequently acceptable to assume that values of competitiveness in 2010 have not been underpinned by the crisis, it would have been preferred to account for that in the empirical strategy. Unfortunately, for such a structural break test to be implemented, a time-series data dimension would have been required, and, once again, this dataset does not allow covering such an issue.

Future research might be also directed to further investigate the competitiveness effects of different typologies of EI by focusing on specific technology fields through a patent-based analysis instead of a survey one. That would allow to look more deeply into the technology of each innovation generated and to differentiate between the competitiveness effects engendered by ER technologies and $EREI$ technologies.

Another interesting future line of research, if these data will be available, would be to apply panel data methodologies on a panel dataset which collects information on EI for more than one subsequent wave. That would also allow controlling for those unobserved firms' heterogeneities that might impact on firms' profitability that we could not completely take into consideration in the current work.

Appendix

Table 3.8: Sector variables and distribution

Description	Sector NACE Rev 2.0	Frequency	Percentage
Agriculture, mining, quarrying	A and B	23	2.16
Food, Beverages, Tobacco	C10-C12	38	3.57
Textile, Leather and wearing app	C13-C15	30	2.82
Wood, paper and printing	C16-C18 (Bench)	51	4.8
Chemicals, Coke and petroleum products	C19-C20	30	2.82
Pharmaceutical industry	C21	7	0.66
Rubber, plastic and o.n.m.p.	C21-C23	67	6.3
Basic and fabricated metals	C24-C25	84	7.9
Computer, Electronic and optical products	C26	72	6.77
Electrical equipment	C27	28	2.63
Machinery and equipment and o.m.	C28, C32, C33	128	12.04
Motor Vehicles and other transport eq.	C29-C30	34	3.2
Furniture	C31	17	1.6
Electricity and Water supply	D-E	93	8.75
Construction	F	13	1.22
Wholesale and retail	G	62	5.83
Transport and communication	H-J	110	10.35
Banking, assurances, renting services	K-L, N	98	9.22
R&D, consulting, education and other se	M, O-T	78	7.34
Total		1063	100

Table 3.9: Differences in the variables' means between operative and full sample

variable	N Operative sample	Mean Operative sample	N Full sample	Mean Full sample
OM	1063	5.614299	2274	5.611258
EREI	1063	0.1063029	6369	0.103941
ER	1063	0.1044214	6313	0.0947252
EI	1063	0.1702728	6400	0.1639063
EAST *	1063	0.332079	7061	0.3084549
SIZE *	1063	4.0275	6319	3.646109
RD *	1063	0.4854186	7061	0.4112732
PC *	1063	0.3941675	7061	0.3444271
HHI *	1063	46.94077	7045	44.67348
LPAT *	1063	-7.488904	7061	-7.834
MS	1063	0.2750892	3391	0.2680772

Variables with * are significantly different between the samples with a confidence level of 95%

Conclusions: summary of results and policy implications

The achievement of the European 2020 policy goals is strictly interrelated with the development, adoption and exploitation of more sustainable production methods and products by firms.

Environmental innovations (EI) are seen in the current work as an instrument that allow to meet the policy target of reducing air emissions, without giving up to economic competitiveness. In other words, EI seems to be central elements for pursuing the greener economy that is placed at the center of the current international agenda.

At the same time, through the adoption of EI by firms, a decoupling between environmental pressure and economic growth may occur, pointing to an economic growth that is more and more independent from environmental damages, as the theory of the environmental Kutznets curve (EKC) sets forth.

The current thesis has the general objective to shed more light on such innovations, given on the one side the central role they have been attributed and, on the other one, the special elements that characterize them (Rennings, 1998; 2000). More specifically, each Chapter identifies the gaps in the previous literature in the field and tries to fill them.

At the centre of the analysis in the whole thesis is the investigation of the drivers and the implications of EI. With the term drivers I refer to all those elements that push or pull firms' decisions to engage in an environmental-innovative activity, meant as the adoption of EI or the generation of environmental technologies as well. With the word implications I mainly refer to the economic consequences in terms of gains or losses that the adoption of EI engender for the firms.

Grounding on previous literature in the fields of the environmental economics and of the economics of innovation, each of the three essays has investigated EI under multiple perspectives. Moreover, the exploitation of heterogeneous data-sources has made the analysis richer.

In developing this work, a big effort has been made in order to properly balance the need of a structural coherence along the Chapters with the need of being original and to add my contribution to the existing literature. Coherence mainly comes from a neo-schumpeterian approach adopted throughout the thesis, which sees (green) innovation and technological advances as creative reactions that are key driving forces for economic change. EI are thus placed at the centre of each of the three empirical analysis, and their determinants, drivers and implications have been analyzed.

Originality comes from the choice to focus in each an every essay on very specific and not investigated (yet) research questions, so that each essay can constitute an autonomous and separately exploitable contribution to the literature in the field.

Each of the three Chapters, through the exploitation of different methodologies and data sources, autonomously contributed to answer original research questions and helps in filling the gaps that have been discovered in previous existing literature.

In the first Chapter it emerged that EI share some similarities with technological and non-technological innovations but they do also differ substantially in the drivers that foster their adoption. In particular their more systemic nature than standard technological innovations has been stressed, as information from partners that are external to the supply chain (e.g. KIBS, research institutions, universities and competitors) has appeared more important (De Marchi and Grandinetti, 2013) and innovation cooperation (e.g. in R&D) has been shown to work more effectively for EI (De Marchi, 2012). Two main implications follow. A general implication is that these differences make the analysis of the determinants of EI appropriate, as the previous literature on the drivers of standard technological and non technological innovations may not perfectly fit the case of EI. Furthermore, the Chapter highlights that some of the building-blocks of the open innovation mode are at stake also in the case of EI. Consequently, not only internal but also external information sources spur the adoption of EI. It derives that, in terms of policy implication, to foster the adoption of EI by firms the policy-maker should also take into consideration the role that networking and external sourcing strategies play.

A policy designed at favoring the search for and exploitation of information coming from the external boundaries of the firm (e.g. business partners, suppliers or universities or research organization) can actually help firms in improving their environmental-innovativeness. Helping knowledge exchanges and networking among firms and other organisations could thus contribute to a sustainable growth in Europe. Removing the barriers that hamper the development of a "green" open innovation mode, such as firms' lack of a network capacity that favors the interaction with external partners, is thus a key policy intervention that would allow the diffusion of EI (Montresor et al., 2013). Policy support to innovation cooperation such as R&D partnership or technology transfer should however not be too wide, as it should also take into account the non-linearities that emerged in the empirical investigation presented in the Chapter, according to which the exploitation of external knowledge sources may be detrimental after a certain threshold.

In Chapter 2 it has been outlined that regulation induces innovations directed towards sustainability but it has been also stressed that countries diverge in the magnitude of their regulatory pressure. The main goal of the Chapter was thus to understand whether inducement mechanisms are at stake also in a context characterized by weak environmental regulatory pressure, such as the Italian one (Haščič et al., 2009).

Exploiting patent data in green technologies of Italian Regions, the empirical analysis performed pointed to the conclusion that regional-sectoral environmental performances positively influence the generation of green knowledge. The main implication of this finding is that an inducement mechanism is at stake also in the Italian context, that is characterized, as anticipated, by weak regulatory pressure. In qualifying these mechanisms of inducement, it has been found that the vertical linkages along the value chain, i.e. those user-producer dynamics that occur along the value chain, do play a central role. The main conclusion is that not only some inducement is at stake also in the presence of weak regulatory pressure, but also that this inducement works through corporate socially responsible behaviors. Those are indeed translated into an increase in the derived demand for cleaner technologies. In other words, the generation of green knowledge, measured by green patents, is stimulated by corporate socially responsible behaviors that are expressed by the derived demand for cleaner technologies.

The main policy implication is that the development of green technologies can be stimulated by raising entrepreneur's awareness of both environmental and also economic relevance of their environmental performances. In order to do that, policies aimed at creating an entrepreneurial culture that attributes a high weight to the environmental performances can stimulate the development of green technologies (e.g. Audretsch, 2007), with the important caveat that a properly designed policy should account for sectoral and regional heterogeneities.

Chapter 3 concludes the analysis on EI by providing an investigation on the economic implications that derive for the firms from their adoption. Measures of firm's profitability have been adopted to analyze the economic implications of EI. Following a firm-level analysis, the main research question was to understand whether it pays or not to be green.

As previous literature focusing on the same research question found very heterogeneous results, the Chapter proposed an original focus to properly deal with this topic.

This original approach consisted in differentiating between typologies of EI, on the one side energy and material saving innovations and on the other one externality reducing innovations. Secondly, the differentiation was made starting from the motivations that drove firms' decision to adopt EI.

The empirical results confirmed the appropriateness of the strategy adopted, as different profitability gains stem from different typologies of innovations and from different motivations behind their adoption. The main general implication is that the category of EI is broad and includes innovations that are intrinsically different. Consequently, a proper differentiation is required to establish the competitiveness effects associated with their adoption.

But what is really relevant from this Chapter are its policy implications.

The most important one is that it pays to be green: green strategies can pay in terms of economic returns, confirming the premises that, in a firm level setting, it is possible to improve firms' environmental performances without giving up to their economic growth.

However, this sentence needs to be better qualified, as it holds for a particular typology of innovation, i.e. those aimed at reducing the energy or material used per unit of output and only when the environmental impact associated is high. When looking at innovations that reduce the negative externalities of production, firms' profitability is instead damaged.

Fostering the adoption of EI by firms might be a good policy target, as it might help both the environment and firms' profitability. Policy makers should however be carefully looking at which typologies of EI they are willing to stimulate, as they engender heterogeneous profitability gains. Moreover, the possibility for a policy intervention as an incentive for firms' innovative activities has been supported by the empirical analysis looking at the role for regulation, finding a confirmation of the widely discussed Porter hypothesis. At the same time, results that have been found for the role of financial grants or subsidies are less promising. This points to the conclusion that also different policies engender heterogeneous innovative responses that are translated into very different profitability outcomes. It is not enough to place an environmental regulation, but this has to be properly targeted and designed to be effective and reach its goals.

Future extension of the research lines that emerged in this thesis can be drawn.

The analysis performed in Chapter 1 can be extended to include those element that favor the absorption of external knowledge by firms, such as R&D and its so-called "second face", that on the one side (first face) is a direct input to innovations and, on the other side (second face), helps reducing the cognitive distance between the firm and its external knowledge sources (Cohen and Levinthal, 1989).A panel analysis on firm level data will then be really helpful in overcoming some reverse causality issues that can arise from the empirical applications proposed. Unfortunately firm level data on the adoption of environmental innovations are not available yet for more than one year (wave), thus making it impossible to perform such an analysis.

Possible future extension of Chapter 2 is to invert the link of causality between environmental performances and green technologies that has been identified in the Chapter. Furthermore, it would have been useful to analyze the longitudinal development of regional air emissions, but at time being, only data for Italian Regions in 2005 are available.

A patent analysis to disentangle the profitability effect of different environmental innovations, identified by their IPC codes, instead of being self-reported (as in Chapter 3) might also be an interesting further extension. It would have also been useful to exploit balance sheet data on profitability instead of self-reported ones (as in the last Chapter), but this was not possible given the anonymization procedures of firm micro data set forth by the statistical offices. Lastly, a relevant extension of the last Chapter would be to look at the economic effects of EI not only for firms but for the whole society, by looking at measures of productivity or employment growth instead of profitability ones.

These developments are already in my research agenda for the very next future.

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