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Linking emission trading to environmental innovation: evidence from the Italian manufacturing industry

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Abstract

This paper examines the different forces underlying the adoption of environmental innovations (EI), with a focus on policy related EI. In particular, exploiting the 2006-2008 wave of the Italian Community Innovation Survey (CIS), we investigate whether the first phase of the European Emissions Trading Scheme (EU-ETS) exerted some effects on EI in CO_2 abatement and energy efficiency controlling for other variables, grouped as internal/external to the firm, and additional environmental regulation factors. Our empirical analyses show that a few factors emerge as particularly relevant such as relationships with other firms and institutions, sectoral energy expenditure intensity, and current and future expected environmental regulation. For the specific role of the EU ETS, we find that, on the one hand ETS sectors are more likely to innovate than non-ETS sectors but on the other hand that sector specific policy stringency is negatively associated with EI, possibly due to anticipatory behavior from early moving innovative firms and some sector idiosyncratic factors.

Keywords: Environmental innovation, EU-ETS, CIS EU data, manufacturing.

1. Introduction

The rapid increase of many environmental problems observed in recent decades calls for innovations that may reduce the environmental impact of economic activity. This is feeding debate on the drivers of environmental innovations (EI). Although there is no standardized definition of EI (cf. Kesidou and Demirel, 2012; Rennings and Rexhauser, 2011; Horbach et al., 2012), the term is used generally to refer to any product, process, organizational, social or institutional innovation that is able to reduce environmental impact and resource use (Kemp, 2010; OECD, 2009; Rennings, 2000; Del Rio, 2009).

Numerous contributions have tried to determine the forces underlying EI. In particular, following the classification proposed by Horbach (2008), Horbach *et al.* (2013) and De Marchi (2012), it is possible to distinguish drivers of EI that are internal (e.g. training activities) and external (e.g. cooperation with other agents) to the firm. Among external drivers, particular attention has been devoted to environmental regulation. Following the seminal contributions by Porter (1991) and Porter and van der Linde (1995), many studies have tested whether and to what extent environmental policies might trigger innovation (cf. Costantini and Mazzanti, 2012, and the literature cited therein). Most contributions find that environmental regulation is the major driving force of EI together with technology push, market pull and firm-specific factors (Rennings and Rexhauser, 2011; Horbach et al. 2012). However, other studies do not support this view (Jaffe and Palmer, 1997; Snyder et al., 2003), and the results for the innovation effects of environmental regulation tend to differ according to the level of analysis (Kozluk and Zipperer, 2013), resulting in a lack of consensus on this issue in the literature.

This paper intends to contribute to this literature by focusing on a specific environmental policy - the European Emission Trading Scheme (EU ETS) - that is receiving increased attention from scholars and policy-makers. The EU ETS involves about 11,000 industry firms in 31 countries and is the first transboundary cap-and-trade system and the largest international scheme for trading greenhouse gases (GHG). Although some shortcomings emerged during its implementation (see section 2.2 below), the EU ETS is currently the most important carbon market and is recognized generally as a suitable prototype for the other ETS that are rapidly spreading worldwide (Ellerman, 2010). The EU ETS can provide a useful experience for new carbon markets, making a thorough analysis of its potential innovation effects particularly important. However, its innovation potential is still debatable; because of its recent origin, quantitative analyses of the EI effects of this policy are scarce in part also due to the problems involved in carrying out robust meso and micro level studies of innovative activity in firms.

To help to fill this gap, we use Italian firm level data from the 5th wave of the Community Innovation Survey (CIS) to examine empirically whether the EU-ETS and its 'stringency' are significantly related to EI in the Italian manufacturing industry, taking account of the internal and external factors that might be correlated with EI. Manufacturing is particularly relevant today given the ‘re-manufacturing target’ of the EU, which aims at accomplishing a 20% share of manufacturing industry in EU GDP by 2020 from its current share of 16% (EEA, 2014).

The analysis of Italian manufacturing provides interesting insights for several reasons: (i) Italy is one of the main GHG emitters, ranked 3rd in Europe and 9th among the Annex I countries (UNFCC, 2014), (ii) its industry structure is based mostly on small-medium enterprises (SME) that have been actively involved in innovation in the past although less so in EI (see below), and (iii) it allows comparison with some other European case-studies that have been examined in the literature on this issue (see below).

The paper is structured as follows. Section 2 reviews the literature on the induced innovation effects of environmental regulation, devoting particular attention to the relationship between EI and the EU-ETS. Section 3 discusses the rationale behind the construction of policy stringency ETS related indicators. Section 4 presents the econometric analyses of EI using CIS 2006-2008 data. Section 5 offers some concluding remarks on the main results of our analyses.

2. Related literature

2.1 Environmental regulation and induced environmental innovation

Analysis of the forces underlying EI builds on the findings of three main research areas: innovation, management science and environmental economics.[1] According to the traditional innovation literature (cf. Carter and Williams, 1959; Kleinknecht and Verspagen, 1990; Schmookler, 1966; Walsh, 1984), innovation is mainly driven by three factors: (1) advances in science and R&D (supply side or technology-pushed innovations), (2) market conditions (demand-pull innovations) and (3) new public policies (regulation-pushed innovations). The supply side (technology push) factor is particularly important in the initial phase of development of a new product (cf. Rosenberg, 1974; Baumol, 2002), while demand from customers, other firms and exports generally play a relevant role in the diffusion phase (Pavitt, 1984; Rehfeld et al., 2007). As to the public policies, they can affect both the innovation itself and its diffusion, taking several forms such as regulations or financial support to research and enterprises.

The literature on EI is largely based on the explanations underlying general innovation, presenting many similarities but also a few important differences with respect to the standard innovation literature (Horbach, 2008). Like the studies on traditional innovation, the literature on EI examines the role of both demand-side and supply-side drivers of EI. Among the latter, particular attention has been devoted to the firms' technological capabilities (Horbach, 2008). Since technological and organizational innovations are likely to develop along complementary lines (Antonioli *et al.*, 2013), the role of environment-related organizational innovations, such as Environmental Management Systems (EMS) and auditing schemes, has also received strong attention among the supply-side drivers of EI (Arimura *et al.*, 2008; Frondel *et al.*, 2004; Wagner, 2007, 2008; Johnstone and Labonne, 2009). Among the demand-side

[1] The classification proposed here is obviously an oversimplification of the existing literature. Much of the work referred to in this section, lie at intersection among the three literature strands identified above. In what follows we group contributions according to the field to which they seem more closely allied.

factors, a crucial role is played by public opinion pressure and current and expected customer demand of environment-friendly products.[2] In particular, empirical studies on German manufacturing firms underline the importance of collaboration with stakeholders in inducing EI (Wagner, 2007).

Despite the importance of demand- and supply-side factors, however, market pull and technology push effects alone are insufficient to foster EI which "in contrast to such technologies as microelectronics and telecommunications, [are] normally not self-enforcing" (Rennings, 1998, p.11). In fact, although EI have the same general drivers as standard innovations, they also have specific features which make it depart from non-environmental innovations and enhance the importance of the role played by the regulation factor for EI (Horbach, 2008; Villiger et al., 2010). In particular, the environmental nature of EI imply a double externality, both in terms of knowledge spillovers (as any other innovation) and in terms of (environmental) public goods (Rennings, 1998; 2000). On the one hand, technological spillovers prevent (eco)innovators from the full appropriation of the value of the innovation; on the other hand, EI tend to benefit the general public by improving environmental quality. While the first externality is common to any other technological innovation, the second is specific to EI. It follows that firms generally have little/no incentive to perform EI unless they are induced (or forced) to do so by a proper environmental regulation. This seems to be confirmed by the empirical literature on this issue, which finds that returns of investing in EI are extremely uncertain. From a meta-analysis of the numerous contributions on this issue (Horváthová, 2010), it turns out that about half of the studies find that the economic returns of "going green" are positive, while the other half conclude that such returns are absent or even negative.[3] Public regulation, therefore, plays a particularly important role as compared to private incentives in the environmental context, which makes EI more regulation-driven than standard innovations. In other words, as argued by Rennings (1998, p.11) the double externality feature characterizing EI implies a second specialty of EI with respect to traditional innovations, that is, "the importance of the regulatory framework as a key determinant of eco-innovative behavior", (what he defines "regulatory push/pull").

A second research area that investigated the drivers of EI is the management science literature on Corporate Social Responsibility (CSR). The studies in this field generally stress the role of demand drivers, underlining that they tend to affect firms' decisions to undertake EI rather than the level of investment (Kesidou and Demirel, 2012). Several studies point out that many firms make minimum investment in EI and adopt CSR policies mainly to improve their "green" image (e.g. Suchman, 1995; Bansal and Hunter, 2003).

[2] Although expectations on demand can play a relevant role for EI, this is not peculiar to such innovations. As a matter of fact, favorable demand conditions have a positive effect on EI (cf. Rehfeld et al 2007; Horbach 2008; Horbach et al 2012) as well as on standard innovations (Schmookler 1966). Moreover, when comparing the drivers of EI with those of other innovations, Horbach (2008) finds that demand expectations are more relevant for the latter.

[3] Results largely depend on the kind of EI taken into account. For instance, Ghisetti and Rennings (2014) find that EI that aim at reducing energy and material use are positively and significantly related to firms' profitability, while the opposite occurs for EI aiming at reducing waste and pollutants, which will not therefore be pursued in the absence of environmental regulation.

As to the environmental economics literature, since the early 1990s there has been heated debate over the economic effects of environmental regulation. In particular, following Porter's controversial hypothesis, many studies have examined whether more stringent environmental regulation promotes EI (see Jaffe et al., 2002; Vollebergh, 2007; Popp 2009 for some surveys of the empirical literature on this issue). As argued by Kozluk and Zipperer (2013), results are partially ambiguous due to data problems, unsatisfactory measures of stringency and estimation strategies. The empirical evidence, moreover, is affected by the level at which the analysis is conducted - firm, industry, or macro level. Firm level studies generally find that more stringent environmental policies tend to boost EI (Arimura *et al.*, 2007; Frondel *et al.*, 2008; Johnstone and Labonne, 2009; Lanoie *et al.*, 2011, Yang *et al*., 2012). However, some studies (Grubb and Ulph, 2002; Kesidou and Demirel, 2012) point out that the reaction to strict regulation can vary across firms. Less innovative firms may be driven to introduce EI in order to comply with the required environmental standards, while more innovative firms may not react to stricter environmental regulation since they tend to undertake EI mainly to enter new markets.

Industry level studies provide more conflicting results. For instance, Jaffe and Palmer (1997) find that environmental regulation has positive effects on R&D expenditure in US manufacturing industries, but not on number of patents which is used as a proxy for EI. In a similar study, Brunnermeier and Cohen (2003), instead, find evidence of a small positive effect on patents in US manufacturing between 1983 and 1992.

Finally, macro-level cross-country studies find a positive relationship between environmental regulation and EI, but with different nuances. In particular, Johnstone *et al*. (2011), using patent data for 77 countries between 2001 and 2007, find that the perceived stringency of environmental regulation has a positive effect on EI. A similar result emerges in De Vries and Withagen (2005), though only one of the three measures of environmental regulation adopted in the paper shows such an effect. Klaassen *et al.* (2005) finds that differences in environmental regulation stringency across countries promotes different EI capabilities, while Popp (2006) underlines that EI decisions are driven by national rather than foreign/international regulation. Leiter *et al*. (2011) focus on 9 manufacturing industries in 21 European countries in the period 1998-2007 and conclude that environmental regulation has a positive, but diminishing impact on investment.

To sum up, most studies find that environmental regulation triggers EI, but the empirical evidence is affected by the level of aggregation and still partially controversial.

2.2 Studies on EU ETS and EI

While the induced EI effects of environmental regulation are the object of a vast literature, there is a smaller subset of studies that focus specifically on the innovation effects of the EU ETS. Analysis of the latter, however, can provide useful insights to improve its design in the future.

Since its introduction in 2005, the EU ETS has experienced several implementation problems, such as the initial overallocation by the National Allocation Plans (Gilbert *et al.*, 2004; Sijm, 2005), hacker attacks and the VAT fraud (Frunza et al., 2010), and large carbon price volatility (see fig. A.1). Some of these problems were addressed by the EU by replacing, on the one hand, the National Allocation Plans with a centralized cap-setting process and, on the other hand, the national registries with a European Union Transaction Log (EUTL) administered centrally by the European Commission. Moreover, while allowances initially could not be hoarded for future use, the EU allowed banking, which is "an important tool to avoid short-term supply-demand imbalances and associated price movements" (Newell et al., 2014).[4] However, the price volatility problem still needs to be fixed. In fact, the price fluctuations that characterized the initial phase of the EU ETS (2005-2007) occurred also in the second and third phases (2008-12 and 2013-20, respectively). While price volatility in the first phase could be ascribed to a learning phase typical of a new market, in the subsequent phases it mainly reflected the drastic emissions reductions due to the economic crisis which caused carbon prices to fall sharply to an average annual price of €4.45 in 2013 (see figure A.2).[5]

This problem was probably further enhanced by the design of the EU ETS. Although banking can certainly reduce compliance costs (Aldy and Stavins, 2012), it also contributed to lower demand (and carbon prices) in the following phases, which possibly exacerbated the oversupply problem generated by the economic crisis.[6].

Many theoretical contributions have analyzed the main features of the EU-ETS, discussing its consequences and problems so far (cf. among others, Requate, 2005; Convery, 2009; Ellerman *et al.*, 2010; Borghesi, 2011; Zetterberg *et al.*, 2012). However, as Kemp (2010) and Kemp and Pontoglio (2011) point out, there are very few large scale empirical investigations of the innovation effects of the EU-ETS, including its pilot phase (2005-2007). Several authors rely on case studies, an approach that can provide interesting insights, but is based mainly on sector specific evidence. For instance, Pontoglio (2010) highlights innovation deficiencies in the Italian paper and cardboard sector; Tomas *et al.* (2010) analyze the Portuguese chemical sector, and Rogge *et al.* (2011) study the energy sectors in Germany.

The studies performed so far provide mixed evidence of the effects of the EU ETS. Several contributions find that the impact of the EU-ETS on innovation in selected sectors has been limited. Hoffman (2007), for instance, concludes that the EU ETS has

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[4] The initial impossibility to transfer unused allowances at a later stage caused the price of the 2007 allowances to fall to zero while the allowances issued in 2008 traded at more than €25 (see fig. A.1).

[5] Price volatility in Phase III has been less pronounced than in Phase II (the price range being €5.84 in Phase III versus €14.36 in Phase II). However, in Phase III the price has been stabilizing around a much lower average than in the previous phase (€4.56, about half the lowest average annual price (€8.12) observed in Phase II).

[6] To counterbalance this problem, the EU has recently revised the functioning of the system by introducing a review of the timetable which determines the supply within phase three of the EU ETS and has postponed auctions of about 900 million allowances planned for 2013, 2014 and 2015 (backloading). While the most recent EU ETS developments are certainly important for the future of this instrument, in the present paper we focus on the innovation effects of the early phase of its implementation since data are not yet available for the later phases of the EU ETS.

affected only short term innovation investments in the German electricity sector. In a similar study involving 42 interviews with German power sector companies, Rogge and Hoffmann (2010, p. 7639) find that "the EU-ETS mainly affects the rate and direction of technological change in power generation technologies, in large-sized coal-based power generating companies". In another important survey of the innovation effects of ETS in the EU power sector, Schmidt *et al.* (2012) conclude that the EU-ETS has limited effect on the innovation activities (adoption and R&D) for power generation technologies. The opposite opinion emerges from the case-study based investigation by Petsonk and Cozijnsen (2007), who conclude that the early phases of the EU ETS have already had a substantial impact on innovation. Similarly, Anderson et al. (2011) - focusing on a small number of Irish firms (27) - find that the EU ETS has been somewhat effective in stimulating technological change.

Whatever the size of the EU ETS innovation effect, however, as Rogge *et al.* (2011, p. 513) point out, "the impact varies significantly across technologies, firms, and innovation dimensions". Similar results emerge from the study by Martin *et al*. (2011) which finds that the propensity to innovate differs significantly across countries, even after controlling for the existing differences in their industry structures. While most of the above-mentioned studies are based on small sample sizes, Martin et al.'s is based on some 800 interviews with managers in 6 European countries. The authors find mixed evidence on ETS related innovation. On the one hand, ETS and non-ETS firms show few differences in relation to process and product innovation; on the other hand, firms that expect a stricter EU ETS cap in Phase III are more likely to engage in product innovation. Calel and Dechezlepretre (2012) provide another contribution based on a large sample. Using a new data set that covers 743 ETS firms in several countries, the authors find that firms subject to the EU ETS have innovated more than unregulated firms, both in general and in terms of low carbon technology. However, more refined estimates[7] show that the EU ETS has not affected the direction of technological change. While Calel and Dechezlepretre's study relies on environment-related patents to capture EI, in what follows we use EI data from the 5th Community Innovation Survey (CIS). We thus analyse innovation data rather than invention (patent) data. One reason is that though patents are a somewhat good proxy of innovation capacity only a fraction of inventions become marketed and diffused as innovations (EEA, 2014).

2.3 CIS-based studies on environmental regulation and EI

A few recent studies conduct CIS-based econometric analyses to test the innovation effects of environmental regulation. In particular, using Flemish CIS EI data, Veugelers (2012) examines the influence of government intervention on the firms' decision to create and/or adopt clean innovation. She finds that policy interventions

[7] To increase the accuracy and robustness of their estimates, the authors match each EU ETS firm in their sample with non-EU ETS firms that showed similar features before 2005 in terms of available resources, demand conditions, regulations etc. This reduces the possibility that the different EI performance derives from factors other than the EU ETS. To rule out other unmeasured differences between ETS and non-ETS firms, the authors employ difference-in-differences estimations which perform a double difference - between the two groups of firms, and over time within each group.

that are well-designed, combining regulation and taxes with subsidies, and are perceived as time consistent have a stronger impact on EI innovation, particularly for reducing CO2. Differently from the present paper, however, Veugelers (2012) does not focus on the ETS but looks at the influence of a bundle of instruments rather than a single policy.[8]

Using German CIS data, Rennings and Rexhauser (2011) find long-term effects of environmental regulation on innovation. However, these effects depend on the type of EI being considered. In particular, the authors find that innovations aimed at increasing energy efficiency and reducing CO2 emissions are mainly triggered by waste disposal and resource recycling regulation introduced in Germany since 1988. Horbach *et al.* (2012) also examine the German case, using 2009 CIS data to evaluate whether different kinds of EI are driven by different factors. Their findings suggest that while the determinants of EI change according to the environmental problem being considered, expected future environmental regulation seems to be a common driver of all environmental product innovations. Unlike our study, however, neither of these analyses of the German case look at EU ETS specific effects.

A contribution related strictly to the present analysis is Aghion et al. (2009). To our knowledge, this is the only study on the ETS effects that looks at CIS data. The authors provide some very interesting insights into the innovation effects of the EU ETS;[9] however, their study relies on descriptive statistics rather than econometric analysis.

The present study is novel in several respects, compared to the contributions referred to above: (i) it analyzes the EI effects of the EU ETS by exploiting the 5th CIS 2006-2008, the first version to include EI-related questions; (ii) it is the first empirical investigation of EU ETS and EI to study Italy, one of the major industrialized countries in the EU28; (iii) compared to case studies and small size samples, it provides an econometric analysis of a large sample (6,843 firms); (iv) it constructs a new and pragmatic stringency indicator by merging sector environmental accounting data with allowances allocation.

For this purpose, we test the ETS innovation effect with particular reference to the start-up phase, that is, the effect of the 2005 allocation of quotas on the adoption of EI in Italy over the time span 2006-2008. The time span between introduction of the ETS and the observed innovation effects -though rather limited in the present context- allows to have a clear time lag between the "policy dose" and the "innovation response", and it is commonly used in the literature (cf. Jaffe and Palmer,1997; Brunnermeier and Cohen, 2003) that evaluate firms' reactions to the implementation of new policies. In addition, in the case of the EU ETS, firms knew well in advance about

[8] The author has actually performed some of the estimations including an ETS dummy as a robustness check, linking the Flemish firms in the CIS data with the EU ETS data. Unfortunately, only 6 Flemish companies turn out to be both in both the CIS and the EU ETS data. Therefore, Veugelers (2012, p. 1774) concludes that her analysis is "unable to evaluate the ETS scheme's influence on firms' innovation behaviour".

[9] In particular, Aghion et al. (2009) argue that the carbon price in the EU ETS has been too volatile to create an appropriate incentive for private green innovations. Gronwald and Ketterer (2012) reach a similar conclusion, pointing out that price volatility and uncertainty about future scenarios possibly has hampered EI.

its implementation since the EU's proposal for a directive and the actual directive date back to 2002 and 2003 respectively. Thus, the present analysis might be capturing anticipatory behavior by ETS firms that could have reacted promptly to the EU ETS by adopting innovations that exonerated them from purchasing costly pollution permits.

In what follows we exclude energy sectors since we intend to focus here on the Italian manufacturing sectors. While the energy sector is certainly of great importance in the ETS context, it represents an outlier with totally different features in terms of innovation and emissions levels, deserving of separate analysis. The present work, therefore, can be seen as complementing previous studies (Schmidt et al., 2012; Rogge et al., 2011) that focus on the energy sector. We also exclude the service sectors from the empirical analysis since they are not generally covered by the EU ETS, a part from a few large energy-consuming installations and incinerators of Italian hospitals and public institutions with a net heat exceeding 20 MW.[10] Moreover, the service sectors are more dependent on national regulations and much more heterogeneous than manufacturing sectors.[11]

3. ETS stringency indicators

Several variables are used in the literature to measure environmental policy stringency, including pollution abatement costs and expenditures (PACE), survey-based perceptions of stringency, policy changes, international environmental treaties, and so on (see Brunel and Levinson, 2013 for a comprehensive review of existing measures). However, as Kozluk and Zipperer (2013) point out, all the proxies for regulation stringency adopted so far have some limitations. The PACE measures, for instance, cannot easily distinguish what share of the expenditure is driven by the environmental regulation and what share by profits, while more event-based approaches (measuring policy changes and new environmental treaties) tend to capture *de jure* aspects of the environmental policies rather than their actual enforcement. For this reason, we propose here an alternative approach based on straightforward comparison of sector emissions and the available allowances. While the proposed proxy is certainly not immune of possible limitations, in our opinion it provides a simple and pragmatic approach that allows us to measure *de facto* policy stringency.

We construct an ETS policy indicator to capture policy stringency in the first allocation phase, which we then employ in the econometric analysis. The stringency indicator is based on the simple ratio of emissions to allocated allowances:

$$s_i = \frac{e_i}{EUA_i}$$

[10] Among the service sectors, the emissions deriving from the aviation sector are now included in the EU ETS, but the aviation sector was not covered by the EU ETS during our observation period as it entered the scheme at a later stage (from 2012).

[11] See, for instance, Conway and Nicoletti (2006) for a comparison of market regulations of different sectors across countries.

where e_i denotes the emissions of sector i and EUA_i the European Union Allowances allocated to sector i. The more emissions sector *i* produces and the lower the level of its allowances, the more stringent is the ETS policy

The proposed indicator has the advantage of being immediately interpretable. In fact, if $s_i > 1$, then the amount of permits at disposal of sector *i* is lower than its emissions level, therefore, the ETS policy is actually stringent for that sector. If, on the contrary, $s_i \leq 1$ then the permits allocated to sector *i* exceed or are equal to its emissions, so the ETS policy is not stringent.

To ensure sensitivity and robustness, we exploit two main sources of information. We use 2000-2005 National Accounting Matrix of Environmental Accounts (NAMEA) sector emissions data (Costantini *et al.*, 2011; Tudini and Vetrella, 2012) released by the Italian National Statistics Agency (ISTAT), to introduce a lag with respect to the innovation information, and data on the allocation decisions derived from official Italian Ministry of the Environment documentation (Ministero dell'Ambiente, 2006).

To conduct sensitivity analyses on our results, we constructed three alternatives measures of *s*: (i) 2005 NAMEA emissions/allocated quotas, (ii) 2000-2005 average NAMEA emissions/ allocated quotas, (iii) Ministry of the Environment reported 2000 emissions/allocated quotas. The estimation results were unchanged therefore, in what follows, we report only the findings relative to the first of these three measures.

In our econometric analysis we first run regressions using a dummy variable that takes the value 1 for sectors subject to the ETS and 0 for all other sectors.[12] When the dummy value is 1, we can compute stringency indicators for the ETS sectors[13] and restrict the econometric analysis to this subset of sectors, introducing the stringency indicator among the model covariates. The use of both the ETS dummy and the stringency indicators among the EI regressors allows us to distinguish the impact on EI deriving from the presence of the ETS, from the effect generated by the (sector specific) stringency of the regulation.

4. The data and the model

In order to analyze EI in the Italian manufacturing industry and to test the effects of the ETS, we exploit data on innovation and CO_2 emissions dimensions from different sources. The main data source is the CIS dataset. The 2008 wave of the CIS was the first to ask about EI adoption in line with the definition of EI developed by the Measuring EI (MEI) project funded by the European Commission's 6th Framework Program (Kemp and Pearson, 2007).[14] The Appendix reports the exact wording of the

[12] See Table A1 for a description of all the sectors included and the corresponding taxonomy. The sectors subject to the ETS are: paper and paper products (industry code 17), coke and refinery (code 19), ceramics and cement (code 23) and metallurgy (codes 24-25).

[13] The value of the stringency indicators s_i (where i denotes the industry code) for the sectors taken into account are as follows: $s_{17} = 1.067$ (paper), $s_{19} = 0.905$ (coke and refined petroleum products), $s_{23} = 1.487$ (ceramic and cement), $s_{24\text{-}25} = 1.470$ (metallurgy).

[14] The data used in this work come from the ISTAT "*Rilevazione statistica sull'innovazione nelle imprese. Anni 2006-2008*". Computations were performed at the ISTAT *Laboratorio per l'Analisi dei Dati Elementari* (ADELE) in compliance with the legislation on the protection of statistical confidentiality and protection of personal data. The results and opinions expressed in the paper are those of the authors who take responsibility for them; they do not represent official opinions.

CIS question which is used to proxy EI. Table 1 reports the descriptive statistics on the average size by industry of the sample firms.

In order to define our ETS policy stringency indicator, as pointed out above, we use two data sources: (i) 2005 NAMEA emissions data (with the average 2000-2005 as an alternative to capture medium run trends), and (ii) the Italian allocation of ETS quotas by sector which we extracted from Ministry documents.[15] These sector data are merged with firm data, which is a standard procedure given the absence of firm level emissions data (see e.g., Cole *et al.*, 2009, who merge individual data on wages with firm/sector pollution data).

Given the binary nature of our two EI dependent variables, we estimate a probit model where the dependent variable Y_i is a dummy that takes the value 1 if firm i introduces an EI (to reduce CO_2 or increase energy efficiency) and 0 otherwise. The full set of covariates is described in Table 2.

We classify our independent variables into three main groups of factors: (i) internal to the firm (e.g. training), (ii) external to the firm (e.g. cooperation), and (iii) policy factors at both regional and national/EU level (e.g. local funding, ETS).

The choice of the covariates taken into account reflects that of similar contributions in the literature, which makes our results comparable with the findings of previous studies. In particular, following Veugelers (2012), we introduced among the covariates a set of variables deriving from a group of questions in the CIS about the role of the following factors underlying EI: current (ENREG) and expected (ENREGF) environmental regulations or environmental taxes; grants or other public financial incentives for EI (ENGRA); existing or expected demand from customers for EI (ENDEM), and voluntary codes of practice used in the sector or sectoral agreements to stimulate eco-friendly practices (ENAGREE). Table 3 reports the correlation matrix between these variables and the ETS stringency indicator (our additional explanatory variable with respect to previous studies).

When presenting the results, these variables are grouped together in the table to help the reader better identify them, and to facilitate comparison with previous studies. However, if we look at the three group classification adopted in the paper, some of these variables can clearly be classified as policy factors (ENREG and ENREGF, ENGRA), and others as factors external to the firm (ENDEM and ENAGREE).

Among the policy factors, we included an ETS dummy for sectors subject to the system and the stringency indicator described above, to differentiate between the roles of the policy and its stringency. Moreover, following Horbach et al. (2012), we introduced among the explanatory variables public funding for innovation (FUND) in addition to the variable ENGRA, to distinguish public support for innovation in general, from that specifically related to EI.

The covariates that are internal to the firm include - in addition to ENDEM and ENAGREE - the role of firm size (proxied by number of employees), labour productivity, and firm training (Rtr) and R&D (Rd) programs. The inclusion of the size variable in the estimation model addresses the hypothesis that large companies may have a greater incentive to innovate to comply with environmental regulation since their larger scale of production causes more pollution. The other internal variables may capture firms’ capacity to absorb external knowledge and ability to

[15] Note that CIS data are anonymous. Therefore, even if firm emissions data were available (which is not the case), matching with EI CIS data would be unfeasible.

improve their technological capabilities. Previous studies (e.g. Horbach, 2008; Horbach et al., 2012; Rennings and Rexhauser, 2011; Veugelers; 2012) provide conflicting results for these variables. For example, firm size was found by Rennings and Rexhauser (2011) to be related positively to most kinds of EI, but Veugelers (2012) finds it to be unrelated to EI in CO2 emissions and energy use (our dependent variables). Similarly, while Horbach (2008) finds R&D to be an important driver of EI, other contributions find it to be unrelated or negatively related to EI (Horbach *et al.*, 2013) and even a barrier to the exploitation of external interactions (Ghisetti *et al.*, 2013).

Among factors external to the firm, we examined whether EI are related to intensity of sector energy expenditure (i.e. per unit of value, EN-EXP). It can reasonably be expected that a high intensity of energy expenditure may trigger EI to reduce the firms' overall production costs. This correlation could be even stronger for ETS firms which have a double incentive to produce EI (to reduce production costs, and to avoid costly purchase of tradable permits). In line with previous contributions (Horbach, 2012; Ghisetti *et al*., 2013), we also examined whether EI activities are correlated to belonging to a business group (GROUP) and to having information relationships with several different sources (the enterprise group, suppliers, clients, competitors etc.). Finally, we included geographic and industry dummies to control for geographic and sector-specific unobserved cross-sectional differences.

Instead of reporting the coefficients, we report the marginal effects of each independent variable (whether continuous or not), that is, the impact of a unit variation in the covariate on the probability of adopting EI.[16]

5. Econometric evidence

We present the results focusing on the two main specifications of EI adoption of interest in this paper: EI related to reducing energy use per unit of output (ECOEN) and reducing CO2 emissions (ECOCO). For each dependent variable, we first describe the findings for internal and external factors and then discuss those for the policy factors.

5.1 Environmental innovations for energy efficiency

5.1.1 Internal and external factors

Tables 4 and 5 present estimation results for EI in energy efficiency, for the whole set of firms, and for the ETS firms only, respectively.

Each table reports findings obtained first excluding (column 1) and then including (column 2) the set of variables deriving from the CIS questions on the potential drivers of EI. The specification in column 3 shows the results obtained when including two additional `environmental related controls': sector energy expenditure per unit of value (among external factors), and Environmental Management Systems (EMS, a firm internal organizational change factor) introduced before 2006.

We reported in the tables the Pseudo-R^2 that measures the goodness of fit of the model. We also add the Count-R^2 or Correctly Classified indicator (CC), that maps the

[16] The STATA command *Dprobit* was used for this (see also Veugelers, 2012). Note that the statistical significance of the coefficients does not change when marginal effects are computed.

(continuous) predicted probabilities deriving from the model into a binary variable (0,1) and then compares the latter with the actual binary outcome variable.[17]

To provide some guidance on the model selection we present some measures that are commonly used to assess model fit, namely, the Akaike information criterion (AIC) and the Bayesian information criterion (BIC). These two criteria take into consideration both the goodness of fit and the complexity of the model introducing a penalty which is an increasing function of the number of estimated parameters. This allows to reduce the risk of overfitting, that is, the artificial increase in the goodness of fit deriving from the introduction of additional parameters. The AIC and BIC use different penalty terms (being higher for the BIC) and have different practical performances and asymptotic properties,[18] but in both cases the preferred model is the one with the minimum AIC (BIC) value. The results of this battery of indicators for the estimated models for EI in energy efficiency show similar performances for specifications 2 and 3, which are preferred with respect to the first one.

As to the external sources, we show that they matter significantly and provide information on multiple factors related to EI adoption. In particular, being part of a business group (GROUP) turns out to be important for EI in energy efficiency for all industries as well as for the subset of ETS firms. This is an interesting finding which confirms that EI activity is heavily embedded in network relationships (Cainelli *et al.*, 2012). A number of specific 'information sources' are relevant for increasing innovation capabilities and innovation adoption. For example, for the whole set of firms, receiving information from other firms in the same group (SENTG) is relevant for energy efficiency (reinforcing the advantages of being part of a business group), while suppliers, clients and conference attendance are the main source of EI for ETS firms.[19]

Among internal sources, we find that the presence of R&D expenditure is never significant (confirming the results in Horbach *et al.*, 2013). In our view, this lack of significance is related to the fact that R&D ultimately is a proxy for general innovation-related capacity.[20] Specific environmental R&D would probably be needed to capture the EI effects of R&D efforts.

The coefficients of all the other internal factors considered turn out to be positive and statistically significant when excluding the set of CIS-related variables on the motivations of EI adoption (column 1). However, only labor productivity still matters when these variables are introduced into the model, (which tends to improve the model's performance as shown by the AIC, BIC and CC indicators reported in the tables). Among the CIS-related variables, current and expected presence of environmental regulation or taxes are particularly highly correlated to EI, for all

[17] When the continuous predicted probability is greater than 0.5 the value of the predicted binary variable is set to 1, while when it is less than 0.5 the value of the predicted binary variable is set to 0. Then the number of correct predictions is computed comparing the actual and the predicted binary variables. The result is divided by total counts.

[18] See Burnham and Anderson (2002) and Yang (2005) for a comparison between the AIC and BIC.

[19] Due to space constraints, each table reports only the coefficients of those 'information sources' that are statistically significant in at least one of the three specifications. The results for the other (non-statistically significant) information sources variables are available upon request.

[20] The evolutionary economics and innovation studies literatures show that R&D is often a factor embodying innovative (absorptive) capacity rather than strong internal firm efforts for comprehensive and environment-specific productivity enhancement. Therefore, it cannot be a determinant of more radical forms of innovation and performance (Breschi *et al.*, 2000).

industry sectors (table 4) and for ETS firms only (table 5), while the other CIS-related variables (customers' demand for EI - ENDEM, grants for EI - ENVGRA and the environmental sectoral agreements - ENAGREE) do not play a role in EI for ETS firms. This would seem to suggest that ETS firms tend to perform EI mainly to comply with environmental regulation, thus emphasizing the crucial importance of policy factors for EI (see below).

Finally, notice that energy expenditure intensity is highly correlated to EI, which is a plausible and expected result: the higher the firms' energy expenditures per unit of value, the higher will be the incentive to find suitable product/process/organizational innovations that allow them to improve their energy efficiency. This result seems consistent with the findings in Horbach *et al.* (2012, p. 117) who conclude that "for energy savings cost savings are the main motivation".

5.1.2 Policy factors

If we consider all industry sectors (table 4), local public support, i.e. regional funding, is a main factor in innovation in energy efficiency: firms that receive public funding (FUND) are more likely to adopt EI. However, if we restrict the analysis to the ETS sectors (table 5), public funding is shown not to be significantly related to EI. Below, we find similar results using CO_2 abatement. This rather surprising result could have several explanations. First, it might reflect the fact that the more innovative ETS sectors considered tend to innovate anyway - whatever the level of the public funds for innovation activity - due to the presence of the ETS, while non-ETS sectors (that have a lower incentive to innovate since they are not part of the ETS) will decide to innovate only if they can rely on public support. Second, in Italy, public support is relatively small, therefore it does not affect the decision to innovate of the most innovative firms, whereas it can make a difference for those firms that generally perform little innovation and may decide to do so to take advantage of regional funding.[21]

Evidence on the core ETS issue is mixed. When we test the ETS effect by including a dummy variable (ETS-DUMMY) in the whole sample, the coefficient is significant and positive (table 4). ETS sectors are more innovative: they are characterized by a higher level of EI than non-ETS sectors. Inclusion in the EU ETS has been seen by these sectors as signaling a policy change that requires a corresponding change in their production technologies that are particularly energy intensive, while non-ETS sectors lagged behind because of the absence of such a signal.

For the sub-sample of the ETS sectors (more than 1,600 firms), we find that ETS stringency is negatively correlated to EI (table 5). The negative association indicates that the ETS is less stringent for sectors with more intense EI activities. This apparently counterintuitive result may reflect the regulator's decision to set more stringent targets to the less innovative sectors in order to induce them to increase their innovation activities. Another possible explanation for the negative relationship

[21] This seems consistent with the findings in the empirical CIS-based literature in this field. Hottenrott and Peters (2011), for instance, find that firms with higher innovation capabilities are more likely to face financing constraints, holding equal internal availability of funds. Therefore, they are used to planning their innovation activities independent of public support, especially in a country like Italy where this support is relatively small. In Italy local funding is often perceived as temporary, and therefore not included in firms' planning activity as a reliable instrument for the future, as confirmed by the interviews discussed below.

between stringency and EI is that the most innovative firms might have adopted an anticipatory behavior: since the idea of the EU-ETS Directive was known well in advance, these firms could have started abating their emissions before the scheme was introduced, thus contributing to reducing their sector stringency level (emissions/allowances). This explanation, which is in line with the crucial role of future expected environmental regulation discussed above, suggests the possible existence of a reverse relationship (in which innovation affects stringency). Due to data constraints, in fact, in this context we can only estimate a reduced form which does not allow us to infer the direction of causality among variables. A closer look at the data suggests an alternative sector-specific explanation so that the observed result might not be counterintuitive, and may have plausible reasons, at least in the current Italian situation. The ceramic and cement sector, in fact, has the highest stringency indicator but the lowest share of firms adopting energy efficiency EI (17% of total firms) compared to the other three sectors (paper and cardboard 18%, coke and refinery 32%, and metallurgy 21%). This suggests the existence of an idiosyncratic sectoral weakness that is particularly evident when we compare Italy to other EU countries: among the biggest EU members, the Italian ceramic and cement sector ranks very low for EI adoption (see table A2).

To get a deeper understanding of this (apparently) counterintuitive result, following the seminal contribution by Greene *et al*. (1989), we adopted a mixed methods research design, conducting several interviews with ETS-sector representatives to complement our econometric analysis.[22]

We conducted four interviews with experts from universities, international and government institutions, five with managers of ETS firms operating in the sectors considered, five with the Industrial Associations corresponding to the sectors,[23] and one with the representative from the Italian Industrial Association (Confidustria). In all cases, we contacted people responsible for the EU ETS within the firm or association.

Although the interviews obviously cover a very limited subset of the Italian firms operating in the ETS-sectors, they can provide some interesting insights into the perceived impact of ETS policy on innovation in the specific sectors involved. The respondents were from sectors with very different emission levels and represent diverse contexts ranging from the relatively clean pulp and paper sector with very low total emissions, to the extremely polluting ceramic and cement sector which is about six times more polluting than the pulp and paper sector (cf. table A3).

Interviews were either face-to-face or by phone, and were recorded subject to the interviewee's permission; interviewers took detailed notes when such permission was not granted.[24]

Since experimental evidence shows that a respondent's answers can be manipulated by simply changing the order of the questions and how they are framed, we used the same questionnaire for all interviewees. The common questions provided the general

[22] As Greene et al. (1989, p. 256) point out, in order to strengthen the validity of the inquiry results, multiple methods should be used to address the same phenomenon since "all methods have inherent biases and limitations". Although our analysis is based mainly on a quantitative method, use of a complementary qualitative method can enhance or cast doubt on the validity of the econometric results. We thank an anonymous referee for useful comments and suggestions on this point.

[23] The industry associations interviewed were: Confindustria Ceramica, AITEC - Associazione Italiana Tecnico Economica Cemento, Assocarta, Unione Petrolifera, ACAI - Associazione Costruttori di Acciaio Italiani.

[24] Interview transcripts are available upon request.

framework to allow comparability among participants' responses. During the interviews, we allowed participants to expand on their answers and provide anecdotal evidence or personal opinions to add relevant detail that would not have emerged from a response to the questions.

The interviewees were asked specifically whether reported changes in EI were due to the EU ETS or due to other factors, including other policies.

Interestingly, all the interviewees stated that the ETS policy was not stringent enough for the ceramic and cement sector. In particular, the interview with the ETS team of the Italian Industrial Association (*Confindustria*, which includes all industry sectors and thus can provide a broader viewpoint) confirmed that the ceramics and cement industries have experienced particular problems compared to other sectors, in reacting to the introduction of the ETS system. These problems are related to the fragmented structure of this sector (many small and medium sized firms organized in districts) and its high pollution intensity. Most firms initially aimed only at being compliant, by buying and using their allowances, and adopted a precautionary approach.

For the paper and cardboard sector, interviews with managers highlighted that the innovation effects of the 1^{st} ETS phase were negligible due to policy uncertainty and price volatility. This seems to confirm the importance of expectations regarding environmental regulation for EI, that emerged from the results for the ENVREGF variable. Interviewees argued that more attention should be devoted to the typology of innovations, which is in line with previous findings (Horbach *et al.*, 2012). For example, respondents pointed out that sectors are highly idiosyncratic, with paper-producing firms which shifted from oil to gas many years ago, and co-generation occurring in most firms (which is not recognized in the ETS scheme). A general stimulus for EI through pricing might not be effective due to high sector technology idiosyncrasy.

Overall, the evidence is mixed. On the one hand, ETS firms innovate through the incentive offered by the new ETS market; on the other hand, ETS intrinsic stringency is negatively associated with innovation, mostly because of sector structural factors that influence the path-dependent patterns of EI diffusion among firms. Negative lock-in effects appear to characterize the ceramic sector, a leading sector of Italian industry, with historically critical environmental performance (Marin and Mazzanti, 2013).

5.2 Environmental innovations for carbon abatement

5.2.1 Internal and external factors

For CO_2 abatement technology adoption, the evidence is similar to that for energy efficiency. The reported indicators (Pseudo-R^2, AIC, BIC and CC) suggest that in general the preferred model specifications are those taking CIS-related variables into account (models 2 and 3), both for all industry sectors (table 6) and for ETS sectors only (table 7). Focusing in particular on the whole set of industry sectors (table 6), even in the case of CO_2 emissions reduction, labor productivity and energy expenditure intensity are positively associated with EI in all the model specifications, capturing the importance of human capital and cost-saving motivations for EI. The main difference with respect to EI in energy efficiency is that being part of a group does not seem to be sufficient for EI in CO_2 abatement, while information/relational factors are even more relevant: external sources play an important role in the adoption of relatively more radical technologies associated with CO_2 abatement. In particular, support provided by industry associations (SPRO), conference participation (SCON) and relationships with public research institutions (SGMT) matter for EI in CO_2 emission reduction. This is coherent with the 'public good' nature of CO_2 abatement which requires breakthrough technologies that are beyond the capabilities of individual firms. In general, information factors correlated with EI adoption seem to differ between CO_2 abatement and energy efficiency, depending upon the different kinds of 'technology adoption'. Both cases, however, highlight the important role of external sources of knowledge for EI.

If we focus on ETS sectors only (table 7), external sources of information are still relevant for EI, but the most important factors are the policy covariates (see below).

Interestingly, the market pull effect proxied by customers' demand for EI does not appear to be related to EI, for either all industry sectors or ETS sectors only. This result, which differs from previous studies (e.g. Veugelers, 2012; Horbach *et al.*, 2012), can probably be ascribed to the relatively low market pressure for cleaner policies and technologies characterizing Italy during the observed period, in which policy commitment on the carbon agenda was not prioritized. Italy also experienced some signs of the incoming 2008-2009 economic downturn well within 2007. Lack of internal demand characterized the whole decade.

The coefficient of EMS is positive and statistically significant only for ETS firms. This is consistent with what would be expected given the quite radical content of EMS as an organizational strategy which is correlated with CO_2 abatement decisions in the sub set of ETS sectors (Wagner, 2007).

5.2.2 Policy factors

Most of the results on the policy factors discussed above for EI in energy efficiency apply also to EI in CO2 abatement. In particular, even in this case, current and expected environmental regulation play a major role for EI, for all industries and for ETS sectors only, confirming the importance of government regulation emphasized by other studies (cf. Veugelers, 2012; Horbach *et al.*, 2012; Rennings and Rexhauser, 2011).

Even in the case of CO_2 abatement innovation, ETS sectors show significantly larger adoption shares in terms of EI than non-ETS sectors (table 6). This may be explained by ETS sectors having more demanding emissions reduction targets than non-ETS sectors, which may induce the former to innovate more than the latter.[25]

Restricting the analysis to ETS firms only, we observe that the results for policy factors obtained for ECOCO (table 7) largely resemble those obtained for ECOEN (table 5) with a few differences that can be ascribed to the different types of technologies involved (e.g. shifting to lower emitting fossil fuels, shifting to renewables, CO_2 capture and storage, etc). However, even in this case, the stringency indicator we test is negatively related to EI. Again, sector data highlight that ceramic/cement firms have the most stringent ETS allocation and are the least innovative in relation to CO_2 abatement (their CO_2 EI adoption rate is 13% vs. 18% for paper and cardboard, and metallurgy, and 25% for coke and refinery). The

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[25] While for ETS sectors the CO_2 emission reduction target (-20% by 2020) was announced since January 2007 (and formally introduced in April 2009), non-ETS sectors were not subject to any formal emissions reduction targets until March 2013. In any case, the non-ETS targets are much less strict (-10% by 2020).

idiosyncratic features of Italian ceramic firms probably hinder adoption of radically new CO_2 abatement technologies, generating a negative effect on EI adoption that is not counterbalanced by the positive impact of support from networking and external sources of knowledge.

6. Conclusions

As previous studies have pointed out (cf. Rennings, 1998; Horbach, 2008), environmental regulation plays a particularly important role among the driving forces underlying EI due to the double externality issue characterizing these innovations.

In order to contribute to the literature on the link between EI and environmental regulation, we focused here on a specific environmental policy that is gaining increasing attention at the international level, the EU ETS. In particular, this paper provides new microeconometric evidence on the role of the EU-ETS for innovation in energy efficiency and CO_2 abatement in manufacturing sectors. Exploiting EI data for Italian firms from the CIS, we investigated the link between the EU ETS and EI controlling for several covariates that can be classified in three groups: internal to the firm, external to the firm, and policy factors.

Our estimates show that EI are associated with various factors, both internal and external to the firm. External forces, that is, knowledge acquisition from several information sources, seem to matter most, with some differences between energy efficiency and CO_2 abatement, probably depending on the radicalness and the content of the innovation. Sectoral intensity of energy expenditures is highly correlated to EI, suggesting a cost saving motivation underlying the innovation activity.

In line with former similar studies, we find that current and future expected regulation is highly correlated to EI. This result corroborates the importance of well-designed, long-term and time-consistent policies to promote the development of cleaner technologies for energy efficiency and CO_2 abatement (Veugelers, 2012).

For the EU-ETS, the empirical evidence provides mixed results on its role in promoting innovation. In the first phase of the scheme, Italian ETS firms were associated with a more widespread adoption of EI in the areas of energy efficiency and CO_2 abatement. However, when we focus on the smaller core set of ETS firms, we find that the policy stringency is negatively related to innovation diffusion, a result that applies to both types of EI taken into account. Three possible explanations are proposed. First, the most innovative firms might have started improving energy efficiency and abating CO2 before the introduction of the EU ETS (which was known about long in advance), thus confirming the role played by future expected environmental regulation in affecting innovation decisions, which emerges from our findings as well as in the related literature. Second, the regulator might increase the policy stringency for the less innovative sectors (giving them a relatively low amount of allowances) so as to lead them to increase their innovation efforts. Third, the negative sign of the relationship between EI and stringency may be partly due to specific sector weaknesses, especially for ceramics and cement firms. Among the polluting sectors taken into account, ceramics shows the highest stringency indicator and the lowest share of firms adopting EI.

To get a deeper understanding of this issue, we conducted interviews with experts, managers, and industry associations. Interesting insights emerged from this complementary qualitative analysis: all interviewees argued that in Italy the ceramic and cement sector was particularly slow to react to the introduction of the emissions scheme, and that during the first phase of the EU-ETS most firms adopted a “wait and see” policy, using the allowances at their disposal rather than investing in new technologies to take advantage of the possibility to sell the permits.

Further research will be needed in the future to enhance the present analysis. In particular, while data constraints limit the time span of the current study to the first EU-ETS phase, it would be important to extend this and investigate whether subsequent more stringent ETS phases have produced more intense EI adoption. Further, new ETS designs might generate more innovation incentives. This is an urgent issue, since the picture is currently very mixed. We have witnessed a drastic reduction in allowance prices over recent years - by about -50% since 2010, associated with still high volatility. This price volatility can generate structural uncertainty about future developments in the ETS market and provide ambiguous signals to firms and sectors. This calls for appropriate amendments to the ETS which might reduce the price volatility and related uncertainty hindering the adoption of the radical innovations currently needed to address the environmental challenge.

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References

Aghion, Ph., Veugelers, R., Serre C., 2009. Cold start for the green innovation machine, Bruegel Policy Contribution, 2009/12, Bruegel, Brussels.

Aldy, J.E., Stavins R.N., 2012. The Promise and Problems of Pricing Carbon: Theory and Experience, Journal of Environment and Development, 21 (2), 152-180.

Anderson B., Convery F., Di Maria C., 2011. Technological Change and the EU ETS: the case of Ireland, IEFE working paper Series, No. 43, IEFE Bocconi University, Milan.

Antonioli D., Mancinelli S., Mazzanti M., 2013. Is environmental innovation embedded within high-performance organisational changes? The role of human resource management and complementarity in green business strategies, Research Policy, 42, 975-988.

Arimura T., Hibiki A., Johnstone N., 2007. An empirical study of environmental R&D: What encourages facilities to be environmentally innovative?, In Johnstone N. (ed) Corporate behavior and environmental policy, Cheltenham, UK, pp.142-173.

Arimura T. Hibiki A. Katayama H., 2008. Is a voluntary approach an effective environmental policy instrument? A Case for environmental management systems, Journal of Environmental Economics and Management, 55, 281-95.

Bansal, P. Hunter, T., 2003. Strategic explanations for the early adoption of ISO 14001. Journal of Business Ethics 46(3), 289-299

Baumol, W.J., 2002. The Free-Market Innovation Machine – Analyzing the Growth Miracle of Capitalism. Princeton University Press, New Jersey.

Borghesi, S., 2011. The European emission trading scheme and renewable energy policies: credible targets for incredible results? International Journal of Sustainable Economy, 3, 3, 312-327.

Breschi, S., Malerba, F., Orsenigo, L., 2000. Technological regimes and Schumpeterian patterns of innovation, The Economic Journal, 110, 388-410.

Brunel, C., Levinson A., 2013. Measuring Environmental Regulatory Stringency, OECD Trade and Environment Working Papers 2013/5, Paris.

Brunnermeier, S., Cohen, M., 2003. The determinants of eco-innovation in US manufacturing industries, Journal of Environmental Economics and Management, 45, 278-293.

Burnham, K.P., Anderson, D.R., 2002. Model Selection and Multinomial Inference: A Practical Information-Theoretic Approach (2nd ed.), Springer-Verlag.

Cainelli G., Mazzanti M., Montresor S., 2012. Environmental innovations, internationalization and local networks, Industry and Innovation 19(8), 2012.

Carter, C.F., Williams, B.R., 1959. Investment in Innovation. Oxford University Press, London.

Cole, M., Elliott, R.J., Lindley J., 2009. Dirty money: Is there a wage premium for working in a pollution intensive industry? Journal of Risk and Uncertainty 39.2, 161-180.

Convery, F.J., 2009. Origins and development of the EU-ETS., Environmental and Resource Economics, 43(3).

Conway, P., Nicoletti, G., 2006. Product market regulation in the non-manufacturing sectors of OECD countries: measurement and highlights, OECD Economics Department Working Paper No. 530/2006, OECD, Paris.

Costantini, V., Mazzanti, M., 2012. On the green side of trade competitiveness? Environmental policy and innovation in the EU, Research Policy, 41, 2.

Costantini, V., Mazzanti, M., Montini, A., 2011. Hybrid Economic-Environmental Accounts, Routledge, London.

Calel R., Dechezlepretre A., 2012. Environmental policy and directed technological change: evidence from the European carbon market, Working Paper FEEM, Milan, n. 22 2012.

Del Rio Gonzalez, P., 2009. The empirical analysis of the determinants for environmental technological change: a research agenda, Ecological Economics, 68, 861-78.

De Marchi, V., 2012. Environmental innovation and R&D cooperation: evidence from Spanish manufacturing firms, Research Policy, 41, 3, 614-23.

De Vries, F. P., Withagen, C., 2005. Innovation and environmental stringency: the case of sulphur dioxide abatement, Discussion Paper Tilburg University, Tilburg.

EEA, 2013a. Trends and projections in Europe 2013. Tracking progress towards Europe's climate and energy targets until 2020, European Environment Agency, Copenhagen.

EEA, 2013b, Annual European Union greenhouse gas inventory. 1990–2011 and inventory report 2013. European Environment Agency, Copenhagen.

EEA, 2014, Green Economy and Policies, European Environment Agency, Copenhagen.

Ellerman, A. D., 2010. The EU's Emissions Trading Scheme: A Proto-type Global System? In J. Aldy and R.N. Stavins (eds.) Post-Kyoto International Climate Policy, Cambridge: Cambridge University Press, 88-118.

Ellerman, A. D., Convery, F. J., de Perthuis, C., 2010. Pricing Carbon: The European Union Emissions Trading Scheme. Cambridge University Press.

Frondel M., Horbach J., Rennings K., Requate T., 2004. Environmental policy tools and firm-level management practices: empirical evidence for Germany, Economics Working Papers 2004,02, Christian-Albrechts-University of Kiel, Department of Economics.

Frondel, M., Horbach, J., Rennings, K., 2008. What triggers environmental management and innovation? Empirical evidence for Germany. Ecological Economics, 66(1), 153-160.

Frunza, M.C., Guegan, D., Thiebaut, F., 2010. Missing trader fraud on the emissions market. Documents de Travail du Centre d'Economie de la Sorbonne 2010.71, Paris.

Ghisetti, C., Marzucchi, A., Montresor, S., 2013. Does external knowledge affect environmental innovations? An empirical investigation of eleven European countries, INGENIO (CSIC-UPV) Working Paper Series No.2013-01, Valencia.

Ghisetti, C., Rennings, K., 2014. Environmental innovations and profitability: How does it pay to be green? An empirical analysis on the German innovation survey, Journal of Cleaner Production, 75, 106-117.

Gilbert, A., Bode, J.W., Phylipsen, D., 2004. Analysis of the National Allocation Plans for the EU Emissions Trading Scheme (London: Ecofys).

Greene J.C., Caracelli V.J., Graham W.F., 1989. Toward a Conceptual Framework for Mixed-Method Evaluation Designs, Educational Evaluation and Policy Analysis, 11, 255-274.

Gronwald M., Ketterer J., 2012. What moves the European Carbon Market? Insights from Conditional Jump Models, CESifo Working Paper No.3795, Center for Economic Studies, Munich.

Grubb, M., Ulph, D., 2002. Energy, the environment and innovation, Oxford Review of Economic Policy, 18 (1), 92-106.

Hoffmann, V.H., 2007. EU ETS and Investment Decisions: The Case of the German Electricity Industry. European Management Journal 25 (6), 464–474.

Horbach, J., 2008. Determinants of eco-innovations, New evidence from German panel data sources, Research Policy, 37, 1, 163-73.

Horbach J., Rammer C., Rennings K., 2012. Determinants of eco-innovations by type of environmental impact. The role of regulatory push/pull, technology push and market pull, Ecological Economics, 78, 112-122.

Horbach, J., Oltra V., Belin, J., 2013. Determinants and Specificities of Eco-Innovations Compared to Other Innovations—An Econometric Analysis for the French and German Industry Based on the Community Innovation Survey, Industry and Innovation, 20:6, 523-543, DOI: 10.1080/13662716.2013.833375

Horváthová, E., 2010. Does environmental performance affect financial performance? A meta-analysis. Ecological Economics, 70 (1), 52-59.

Hottenrott, H., Peters, B., 2011. Innovative Capability and Financing Constraints for Innovation: More Money, More Innovation? Review of Economics and Statistics 94, 1126–1142.

Jaffe, A.B., Palmer, K., 1997. Environmental regulation and innovation: A panel data study, The Review of Economics and Statistics, 79 (4), 610-619.

Jaffe, A.B., Peterson, S.R., Portney, P.R., Stavins, R.N., 2002. Technological change and the environment, Environmental and Resources Economics, 22, 41-69.

Johnstone, N., Labonne J., 2009. Why do manufacturing facilities introduce environmental management systems? Improving and/or signaling performance?, Ecological Economics, 68, 719-30.

Johnstone, N., Haščič, I., Poirier, J., Hemar, M., Michel, C., 2011. Environmental policy stringency and technological innovation: evidence from survey data and patent counts. Applied Economics, 44, 2157-2170.

Kemp, R., 1997. Environmental Policy and Technical Change, Edward Elgar, Cheltenham.

Kemp, R., 2010. Eco-innovation: definition, measurement and open research issues, Economia Politica, XXVII, 3, 397-420.

Kemp, R., Pearson, P., 2007. Final report of the MEI project measuring eco innovation, UM MERIT, Maastricht.

Kemp, R., Pontoglio, S., 2011. The innovation effects of environmental policy instruments. A typical case of the blind men and the elephant, Ecological Economics, 72, 15, 28-36.

Kesidou, E., Demirel, P., 2012. On the drivers of eco-innovations: Empirical evidence from the UK, Research Policy, 41 (5), 862-870.

Klaassen, G., Miketa, A., Larsen, K., Sundqvist, T., 2005. The Impact of R&D on Innovation for Wind Energy in Denmark, Germany and the United Kingdom. Ecological Economics 54(2-3), 227-240.

Kleinknecht, A., Verspagen, B., 1990. Demand and Innovation: Schmookler Re-examined. Research Policy 19, 387-394.

Kozluk, T., Zipperer V., 2013. Environmental policies and productivity growth – A critical review of empirical findings, Economics Department Working Paper No. 1096, OECD, Paris.

Lanoie P., Laurent-Lucchetti J., Johnstone N., Ambec S., 2011. Environmental policy, Innovation and Performance: New Insights on the Porter Hypothesis, Journal of Economics and Management Strategy, 20(3), 803-842.

Leiter, A.M., Parolini, A., Winner H., 2011. Environmental regulation and investment: Evidence from European industry data, Ecological Economics, 70, 759-770.

Marin G., Mazzanti M., 2013. The evolution of environmental and labour productivity dynamics, Journal of Evolutionary Economics, 23, 2, 357-99.

Martin R., Muuls M., Wagner U., 2011. Carbon markets, carbon prices and innovation: evidence from interviews with managers, paper presented at the EAERE conference, Rome, 29 June- 2 July 2011.

Ministero dell'Ambiente e del Territorio, 2006. Assegnazione e rilascio delle quote di CO_2 per il periodo 2005-2007 ai sensi di quanto stabilito dall'articolo 11, paragrafo 1 della direttiva 2003/87/ce del Parlamento Europeo e del Consiglio, DEC/RAS/074/2006, Roma.

Newell R.G., Pizer W.A., Raimi D., 2014. Carbon Market Lessons and Global Policy Outlook, Science, 343, 1316-17.

OECD, 2009. Sustainable Manufacturing and Eco-Innovation: Framework, Practices and Measurement – Synthesis Report. OECD, Paris

Pavitt, K., 1984. Sectoral patterns of technical change: Towards a taxonomy and a theory. Research Policy 13, 343-373.

Petsonk A., Cozijnsen J., 2007. Harvesting the Low-Carbon Cornucopia: How the European Union Emissions Trading System (EU ETS) is Spurring Innovation and Scoring Results, Environmental Defense Report, 14 March 2007.

Pontoglio, S., 2010. An early assessment of the influence on eco-innovation of the EU Emissions Trading Scheme - Evidence from the Italian paper industry. In: Mazzanti M., Montini A, (eds.), Environmental Efficiency, Innovation and Economic Performance, Routledge.

Popp, D., 2006. International innovation and diffusion of air pollution control technologies: the effects of NO_X and SO_2 regulation in the US, Japan, and Germany, Journal of Environmental Economics and Management, 51, 46-71.

Popp, D., Newell, R.G., Jaffe, A.B., 2009. Energy, the environment and technological change, NBER Working Paper No.14832.

Porter, M., 1991. America's green strategy, Scientific American, 264 (4), 168.

Porter, M., Van der Linde, C., ,1995. Toward a new conception of the environment-competitiveness relationship, Journal of Economic Perspectives, 9, 4, 97-118.

Rehfeld, K.M., Rennings, K., Ziegler, A., 2007. Integrated product policy and environmental product innovations: An empirical analysis. Ecological Economics, 61, 91-100.

Rennings, K., 1998. Towards a Theory and Policy of Eco-Innovation – Neoclassical and (Co-)Evolutionary Perspectives. ZEW Discussion Papers 98-24. http://hdl.handle.net/10419/24575.

Rennings, K., 2000. Redefining innovation: Eco-innovation research and the contribution from ecological economics. Ecological Economics 32 (2), 319-332.

Rennings, K., Rexhauser, S., 2011. Long-Term Impacts of Environmental Policy and Eco-Innovative Activities of Firms, International Journal of Technology, Policy and Management, 11 (3/4), 274-290.

Requate T., 2005. Dynamic incentives by environmental policy instruments: a survey, Ecological Economics.

Rogge K., Schneider M., Hoffmann V., 2011. The innovation impact of the EU Emission trading system -- findings of company case studies in the German power sector, Ecological Economics, 70, 513-23.

Rogge K., Hoffmann V., 2010. The impact of the EU Emission trading system on the sectoral innovation system of power generation technologies: findings for Germany, Energy Policy, 38, 7639-52.

Rosenberg, N., 1974. Science, invention and economic growth. The Economic Journal, 84, 90-108.

Schmidt, T.S., Schneider, M., Rogge, K.S., Schuetz, M.J.A., Hoffmann, V.H., 2012. The effects of climate policy on the rate and direction of innovation: A survey of the EU ETS and the electricity sector. Environmental Innovation and Societal Transitions 2, 23-48.

Schmookler, J., 1966. Invention and economic growth. Harvard University Press, Cambridge, Mass.

Sijm, J., 2005. The interaction between the EU emissions trading scheme and national energy policies, Climate Policy, 5.

Snyder L., Miller N., Stavins R., 2003. The effects of environmental regulation on technology diffusion: The case of chlorine manufacturing, The American Economic Review, 93 (2), 431-435.

Suchman, M. 1995. Managing Legitimacy: Strategic and Institutional Approaches. Academy of Management Review 20 (3), 571-610.

Tomas, R., Ribeiro, F. R., Santos, V., Gomes, J., Bordado, J., 2010. Assessment of the impact of the European CO_2 emissions trading scheme on the Portuguese chemical industry. Energy Policy, 38(1):626-632.

Tudini A, Vetrella G., 2012. NAMEA: from pioneer work to regulation and beyond, in Costantini V. Mazzanti M. Montini A. (eds) Hybrid Economic Environmental Accounts, Routledge.

UNFCC, 2014. United Nations Framework Convention on Climate Change: GHG data URL: http://unfccc.int/di/FlexibleQueries/Event.do?event=showProjection

Veugelers R., 2012. Which policy instruments to induce clean innovating?, Research Policy, 41, 10, 1770-78.

Villiger, A.R., Wüstenhagen, R., Meyer, A., 2000. Jenseits der Öko-Nische. [Beyond the ecological niche.] Basel, Switzerland: Birkhäuser.

Vollebergh, H., 2007. Impacts of environmental policy instruments on technological change. OECD Environment Directorate Working Paper.

Wagner M., 2008. National culture, regulation and country interaction effects on the association of environmental management systems with environmentally beneficial innovation, Business strategy and the environment, 18, 2, 122-136.

Wagner, M., 2007. On the relationship between environmental management, environmental innovation and patenting: Evidence from German manufacturing firms, Research Policy, 36, 10, 1587-1602.

Walsh, V., 1984. Invention and innovation in the chemical industry: Demand-pull or discovery-push? Research Policy, 13 (4), 211-234.

Yang, Y., 2005. Can the strengths of AIC and BIC be shared?. Biometrika, 92, 937-950. DOI: 10.1093/biomet/92.4.937

Yang C.H., Tseng Y.H., Chen C.P., 2012. Environmental regulations, induced R&D and productivity: Evidence from Taiwan’s manufacturing industries”, Resource and Energy Economics, 34, 514-532.

Zetterberg L, Wrake M., Sterner T., Fischer C., Burtraw D., 2012. Short run allocation of emissions allowances and long-term goals for climate policy, Ambio, 41, 23-32.

Tables

Table 1: Sample description

	ECOEN		**ECOCO**		**Total**
Industry	**N.**	**%**	**N.**	**%**	**N.**
10	70	15,0	62	13,3	467
11	23	21,5	24	22,4	107
12	1	100,0	1	100,0	1
13	49	16,1	41	13,4	305
14	34	8,6	34	8,6	397
15	26	12,7	22	10,8	204
16	53	15,6	41	12,1	339
17	41	21,6	35	18,4	190
18	50	12,0	40	9,6	415
19	18	32,1	14	25,0	56
20	39	26,2	36	24,2	149
21	18	23,7	11	14,5	76
22	79	17,8	52	11,7	445
23	63	16,6	51	13,5	379
24	54	21,4	46	18,3	252
25	131	17,8	89	12,1	736
26	32	19,8	27	16,7	162
27	46	23,6	34	17,4	195
28	100	21,8	88	19,2	458
29	37	31,4	29	24,6	118
30	16	24,6	14	21,5	65
31	56	19,8	43	15,2	283
32	49	17,7	35	12,6	277
33	54	13,3	46	11,3	407
Total	**1139**	17,6	**915**	14,1	**6483**

Table 2: Descriptive statistics

	Mean	*Std. Dev*
dependent variables		
Ecoen (Energy reduction per unit of output)	0.175	0.380
Ecoco (CO_2 reduction)	0.141	0.348
Factors 'external to the firm'		
Sentg (information relationships – enterprise group)	0.432	0.495
Ssup (information relationships - suppliers)	0.365	0.481
Scli (information relationships – clients)	0.284	0.451
Scom (information relationships – competitors)	0.151	0.358
Sins (information relationships – private research institutions)	0.209	0.406
Suni (information relationships – university)	0.078	0.268
Sgmt (information relationships – public research institutions)	0.039	0.195
Scon (information relationships – conferences)	0.214	0.410
Sjou (information relationships – journals)	0.144	0.351
Spro (information relationships –industrial association services)	0.125	0.331
Group (membership to business groups)	0.297	0.457
ln(en-exp) (energy expenditure per unit of value)	-3.682	0.665
Factors 'internal to the firm'		
RTR (training programmes in the firm)	0.259	0.438
lprod06 (labour productivity in 2006)	11.88	0.816
R&D (R&D programmes in the firm)	0.305	0.460
Policy factors		
Fund (public funding to innovation)	0.125	0.331
ets-dummy (sector subject to ets)*	0.248	0.432

*dummy variable. Values for stringency indicators: s_{17} = 1.067 (paper), s_{19} = 0.905 (coke and refined petroleum products), s_{23} = 1.487 (ceramic and cement), s_{24-25} = 1.470 (metallurgy)

Table 3: correlation matrix (ETS stringency and CIS-related variables)

Legend: ENREG= current environmental regulations or environmental taxes; ENREGF= expected environmental regulations or environmental taxes; ENGRA= grants or other public financial incentives for EI; ENDEM= existing or expected demand from customers for EI; ENAGREE= voluntary codes of practice used in the sector or sectoral agreements to stimulate eco-friendly practices.

	STRINGENCY	ENREG	ENREGF	ENGRA	ENDEM	ENAGR
STRINGENCY	1,000					
ENREG	0,037	1,000				
ENREGF	0,017	0,497	1,000			
ENGRA	0,006	0,290	0,340	1,000		
ENDEM	-0,018	0,308	0,358	0,337	1,000	
ENAGR	0,001	0,301	0,335	0,301	0,439	1,000

Table 4: ECOEN regressions – all industry sectors

Estimation method: dprobit	[1.]		[2.]		[3.]	
	dF/dx	*t-value*	*dF/dx*	*t-value*	*dF/dx*	*t-value*
Ln(employees)	0.010*	1.69	-0.006	-1.01	-0.007	-1.15
RTR	0.046***	3.76	0.013	1.13	0.014	1.22
Group	0.024**	2.10	0.024**	2.06	0.024**	2.03
R&D	0.0002	0.03	-0.014	-1.30	-0.015	-1.39
Fund	0.051***	4.41	0.043***	3.59	0.044***	3.69
Ln(productivity)	0.021***	2.93	0.013**	2.12	0.012**	1.98
Sentg	0.060***	4.01	0.039**	2.41	0.039**	2.35
ETS – dummy	***0.052****	***8.28***	***0.045****	***3.56***	…	…
Enreg	…	…	0.154***	11.18	0.153***	11.02
Enregf	…	…	0.180***	12.70	0.180***	12.63
Engra	…	…	0.040***	2.70	0.039**	2.57
Endem	…	…	-0.007	-0.54	-0.009	-0.69
Enagr			0.045***	3.10	0.047***	3.21
EMS	…	…	…	…	0.012	0.89
en-exp	…	…	…	…	1.616***	121.04
Geographic dummy	Yes		Yes		Yes	
Industry dummy	Yes		Yes		Yes	
N. obs.	6,483		6,483		6,483	
Pseudo R^2	0.051		0.147		0.147	
AIC	5737.7		5173.8		5106.9	
BIC	5819.0		5289.0		5221.9	
CC	82.4%		83.4%		83.5%	

*** significant at 1%; ** significant at 5%; * significant 10%; Standard errors are clustered at industry level (24 sectors). AIC= Akaike information criterion, BIC= Bayesian information criterion, CC= Correctly Classified

Table 5: ECOEN regressions: only ETS industries

Estimation method: dprobit	[1.]		[2.]		[3.]	
	dF/dx	*t-value*	*dF/dx*	*t-value*	*dF/dx*	*t-value*
Ln(employees)	0.010	0.57	-0.015	-1.17	-0.015	-1.26
RTR	0.026	1.46	-0.010	-0.93	-0.010	-0.92
Group	0.022	1.24	0.034**	2.37	0.034**	2.36
R&D	-0.001	-0.04	-0.013	-0.53	-0.013	-0.52
Fund	0.012	0.67	0.019	0.83	0.019	0.83
Ln(productivity)	0.023**	2.19	0.010	1.25	0.009	1.05
Ssup	0.027**	2.11	0.019	1.28	0.019	1.26
SCLI	0.060***	5.29	0.037**	2.43	0.036**	2.40
SCON	0.072***	3.00	0.060**	2.55	0.060**	2.60
ETS-stringency	***-0.009****	***-7.55***	***-0.016****	***-8.41***	***-0.016****	***-8.71***
Enreg	…	…	0.161***	6.23	0.160***	6.17
Enregf	…	…	0.170***	12.04	0.169***	11.39
Engra	…	…	0.044	1.50	0.044	1.48
Endem	…	…	0.010	0.26	0.009	0.24
Enagr	…	…	0.032	1.30	0.031	1.26
EMS	…	…	…	…	-0.010	-0.51
Geographic dummy	Yes	Yes	Yes	Yes	Yes	Yes
Industry dummy	Yes	Yes	Yes	Yes	Yes	Yes
N. obs.	1.613		1.613		1.613	
Pseudo R^2	0.047		0.134		0.134	
AIC	1503.5		1366.6		1366.4	
BIC	1525.1		1388.2		1388.0	
CC	80.6%		81.2%		81.3%	

*** significant at 1%; ** significant at 5%; * significant 10%;
Note: standard errors are clustered at industry level (5 sectors)
AIC= Akaike information criterion, BIC= Bayesian information criterion, CC= Correctly Classified

Table 6: ECOCO regressions – all industry sectors

Estimation method: dprobit	[1.]		[2.]		[3.]	
	dF/dx	*t-value*	*dF/dx*	*t-value*	*dF/dx*	*t-value*
Ln(employees)	0.010**	1.99	-0.004	-1.01	-0.005	-1.22
RTR	0.035***	3.77	0.005	0.73	0.005	0.70
Group	0.019	1.63	0.015	1.40	0.015	1.36
R&D	0.022**	2.20	0.006	0.69	0.004	0.48
Fund	0.028**	2.21	0.022*	1.65	0.023*	1.70
Ln(productivity)	0.024***	4.49	0.015***	2.96	0.014***	2.76
Sgmt	0.050***	2.75	0.028*	1.70	0.026	1.53
Scon	0.042***	4.21	0.026***	2.72	0.028***	2.87
Sjou	-0.022*	-1.66	-0.037***	-3.37	-0.037***	-3.37
Spro	0.048***	3.78	0.027**	2.20	0.028**	2.24
ETS – dummy	***0.034****	***4.90***	***0.025****	***3.99***	…	…
Enreg	…	…	0.149***	11.45	0.148***	11.35
Enregf	…	…	0.169***	12.09	0.166***	11.88
Engra	…	…	0.017	1.21	0.018	1.26
Endem	…	…	0.005	0.47	0.004	0.45
Enagr	…	…	0.049***	3.27	0.048***	3.12
EMS	…	…	…	…	0.019	1.39
en-exp	…	…	…	…	1.272***	95.41
Geographic dummy	Yes		Yes		Yes	
Industry dummy	Yes		Yes		Yes	
N. obs.	6,483		6,483		6,483	
Pseudo R^2	0.057		0.179		0.178	
AIC	5003.7		4371.7		4318.2	
BIC	5105.4		4507.3		4453.5	
CC	85.9%		86.8%		86.9%	

*** significant at 1%; ** significant at 5%; * significant 10%;
Note: standard errors are clustered at industry level (24 sectors)
AIC= Akaike information criterion, BIC= Bayesian information criterion, CC= Correctly Classified

Table 7: ECOCO regressions: only ETS industries

Estimation method: dprobit	[1.]		[2.]		[3.]	
	dF/dx	*t-value*	*dF/dx*	*t-value*	*dF/dx*	*t-value*
Ln(employees)	0.016	1.57	-0.006	-0.85	-0.008	-1.14
RTR	0.031	1.43	-0.003	-0.18	-0.004	-0.21
Group	-0.004	-0.19	0.002	0.10	0.001	0.06
R&D	0.017	1.02	0.003	0.19	0.005	0.26
Fund	-0.012	-0.44	-0.010	-0.32	-0.010	-0.33
Ln(productivity)	0.030***	4.55	0.015	1.46	0.012	1.27
Scon	0.056***	6.52	0.036**	2.25	0.035**	2.13
Spro	0.062**	2.50	0.033*	1.65	0.033*	1.71
ETS-stringency	***-0.022****	***-6.20***	***-0.024****	***-5.34***	***-0.025****	***-5.43***
Enreg	…	…	0.119***	4.75	0.117***	4.88
Enregf	…	…	0.205***	10.16	0.199***	10.59
Engra	…	…	0.051***	4.64	0.056***	4.83
Endem	…	…	-0.004	-0.70	-0.008	-1.47
Enagr	…	…	0.031	1.02	0.028	0.89
Ems	…	…	…	…	0.053**	1.96
Geographic dummy	Yes	Yes	Yes	Yes	Yes	Yes
Industry dummy	Yes	Yes	Yes	Yes	Yes	Yes
N. obs.	1.613		1.613		1.613	
Pseudo R^2	0.054		0.179		0.183	
AIC	1274.5		1107.3		1101.9	
BIC	1296.1		1128.9		1123.4	
CC	85.4%		85.2%		85.9%	

*** significant at 1%; ** significant at 5%; * significant 10%;
Note: standard errors are clustered at industry level (5 sectors)
AIC= Akaike information criterion, BIC= Bayesian information criterion, CC= Correctly Classified

Appendix

Community Innovation Survey (CIS) questionnaire: definition of environmental innovation and variables used

Question 10. Innovations with environmental benefits
An environmental innovation is a new or significantly improved product (good or service), process, organizational method or marketing method that creates environmental benefits compared to alternatives.
• The environmental benefits can be the primary objective of the innovation or the result of other innovation objectives.
• The environmental benefits of an innovation 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.

10.1 During the three years 2006 to 2008, did your enterprise introduce a product (good or service), process, organisational or marketing innovation with any of the following environmental benefits?

Yes No

Environmental benefits from the production of goods or services within your enterprise
Reduced energy use per unit of output ==> *ECOEN*
Reduced CO_2 ‘footprint’ (total CO_2 production) by your enterprise ==> *ECOCO*

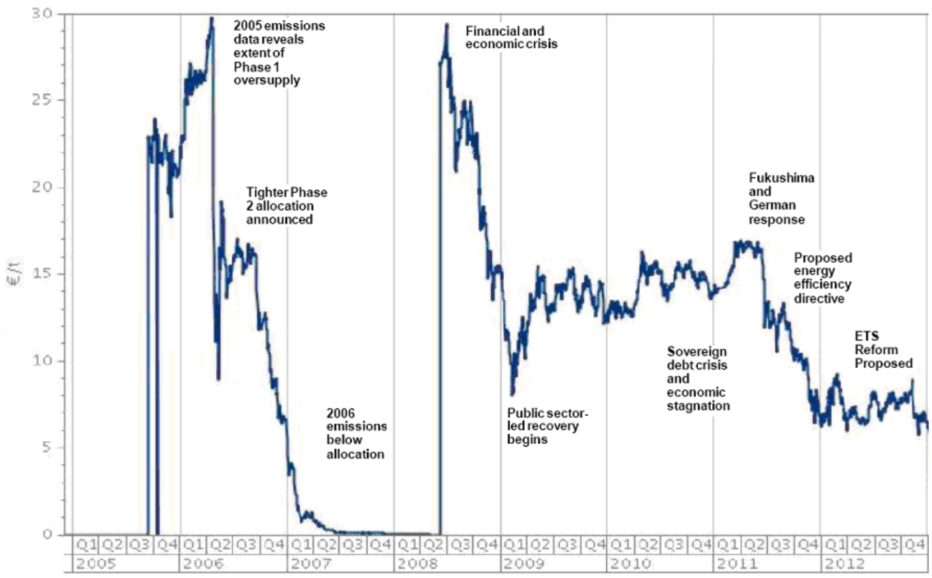

Figure A1
Source: authors’ own elaboration based on Point Carbon (2013) data


ICE European Emissions EUAINDEX
8.50
8.25
8.00
7.75
7.50
7.25
7.00
6.75
6.50
6.25
6.00
5.75
5.50
5.25
5.00
4.75
4.50
4.25
4.00
3.75
3.50
3.25
3.00
2.75
2.50
Jan-2013
Apr-2013
Jul-2013
Oct-2013
Jan-2014
Apr-2014
© ICE Data.

Figure A2

Table A1: Industry code description

Industry code	Description
10	Manufacture of food products
11	Manufacture of beverages
12	Manufacture of tobacco products
13	Manufacture of textiles
14	Manufacture of wearing apparel
15	Manufacture of leather and related products
16	Manufacture of wood and of products of wood and cork, except furniture
17	Manufacture of paper and paper products
18	Printing and reproduction of recorded media
19	Manufacture of coke and refined petroleum products
20	Manufacture of chemicals and chemical products
21	Manufacture of basic pharmaceutical products and pharmaceutical preparations
22	Manufacture of rubber and plastic products
23	Manufacture of other non-metallic mineral products
24	Manufacture of basic metals
25	Manufacture of fabricated metal products, except machinery and equipmen
26	Manufacture of computer, electronic and optical products
27	Manufacture of electrical equipment
28	Manufacture of machinery and equipment n.e.c.
29	Manufacture of motor vehicles, trailers and semi-trailers
30	Manufacture of other transport equipment
31	Manufacture of forniture
32	Other manufacturing
33	Repair and installation of machinery and equipment

Table A2: Leaders in EI adoption in the EU among Sweden, Italy, Germany, France, The Netherlands (source CIS)

Sectors	Leader CO_2 innovation	Leader emission innovation	CO_2 innovation (Ranking Italy) (1-5)	Emission innovation Ranking Italy (1-5)
Manufacturing	Germany	Germany	5	3
Industry (except construction)	Germany	Germany	5	3
Financial and insurance activities	The Netherlands	France	5	4
Financial service activities, except insurance and pension funding	France	France	5	3
Service of the business economy	Sweden	France	4	3
Insurance, reinsurance and pension funding, except compulsory social security	Sweden	The Netherlands	5	3
Manufacture of basic metals	Germany	Germany	5	3
Manufacture of basic metals and fabricated metal products, except machinery and equipment	Germany	Germany	2	3
Manufacture of chemicals and chemical products	Germany	Germany	5	5
Manufacture of coke and refined petroleum products	Germany	Germany	3	4
Manufacture of fabricated metal products, except machinery and equipment	Germany	Germany	2	2
Manufacture of other non-metallic mineral products	Germany	Germany	4	5
Manufacture of paper and paper products	Germany	Germany	5	5
Air transport	Germany	Germany	4	5

Table A3: Verified emissions in the examined EU-ETS sectors during the period 2006-2008

Sector	2006	2007	2008
Coke and refineries	28185,69	28912,06	27681,06
Pig iron or steel	13709,98	13890,76	15528,64
Ceramics and cement	31343,17	31951,32	29180,71
Pulp, paper and board	5053,85	5007,03	4756,43
Total Emissions under EU ETS	227439,47	226405,41	220676,33
Non EU-ETS Emissions	346600	337600	320500

Source: authors' elaboration on EEA (2013 a,b)