Environmental innovation adoption, sector upstream/downstream integration and policy. Evidence from the EU

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Abstract

Eco innovations in the climate change realm requires pressures and knowledge from outside the firm's and sector's boundaries. The role of policies is well known, as a tool that potentially tackle two externalities: innovation and environmental market failures. Sector integration is also increasingly relevant for understanding the economic, environmental and innovation performances of countries. We integrate these two perspectives to provide evidence on the policy effects behind the adoption of eco innovations in EU sectors. We take a sector perspective by exploiting EU CIS data over 2006-2008. By using past CO2 emission intensity (CO2 on value) as a proxy of policy stringency, we find that emission intensive sectors are more likely to adopt CO2-related eco-innovations. The aforementioned results are valid for both the economy as a whole and for industrial sectors specifically. We additionally show that not only environmental policies are important to sustain EI adoptions. Other 'external' drivers play a role. Looking at the role of inter sector integration and knowledge sources, we observe that sectors with more emission intensive upstream 'partners' eco-innovate more to reduce their CO2 footprints. The positive and significant effect of upstream emission intensity (supplier's emission intensity) is actually stronger than the effect of 'direct' CO2 emission intensity (policy effect).

Keywords: Environmental innovations, sector integration, induced effects, innovation adoption, NAMEA; Input output, EU

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1. Introduction

Innovation is a crucial factor to achieve a sustainable and competitive economic development. Technological progress is the only exogenous driver of long run growth in income per capita in classic Solow-like models; Endogenous growth theory has emphasised the role of R&D and human capital as main forces behind countries (heterogeneous) performances; neo Schumpeterian evolutionary theory poses innovation in a broad techno-organisational meaning at the heart of economic systems development. In studies of environmental and economic performances, innovations – technological, organisational, behavioural - has gained increasing relevance as a key factor to obtain sustainable transitions (Costantini et al., 2013; Mazzanti and Montini, 2010; van den Bergh, 2007).

Environmental innovations (EI) are crucial to creating synergies between sustainability and competitiveness towards a greener economy (EEA, 2013). This is a fact that can be traced back to the pillars of growth theory in economics, revitalised by the advent of thinking oriented toward sustainable policy practices in the final part of the last century. Innovation *per se* is a keystone in the EU Lisbon agenda, which should create the pre-conditions for achieving and integrating social, economic and environmental goals by 2020 and in the longer term (Gilli et al., 2013). On a theoretical ground, the literature that addresses the dynamics of EI has developed following classical research on the static and dynamic efficiency of regulatory instruments (economic vs. command and control, fiscal tools and emission trading), including the effects of innovation spurred by the regulatory stimulus (Hahn and Stavins, 1992; Goulder and Parry, 2008). More recently, an evolutionary economics setting has also been adopted (Mulder and Van den Bergh, 2001), which is focused on the co-evolution of innovation, policy and economic dynamics in socio-bio-economic systems (Kemp, 1997; Kemp, 2010). Advancement towards a greener and more competitive economy is possible only if all components of social welfare are taken into account by firms, stakeholders, policy makers. Environmental innovations (Rennings, 2000, 1998) are a key factor, as it is well known that sustainable economic growth depends upon a constant investment in technological and new organisational/labour related ways of managing production. The potential of EI must be enriched and embedded within a very broad set of related factors as well as economic, social and environmental effects. One of the most recent definitions of eco-innovation defines it as the production, application or use of a product, service, production process or management system new to the firm adopting or developing it, and which implies a reduction in environmental impact and resource use (including energy) throughout its life-cycle (Kemp, 2010). The drivers of EI are multifaceted and touch upon various spheres of society and policy making (Horbach et al., 2012). Well-designed policies can spur EI if firms believe that innovation offsets are greater than regulatory costs (Costantini and Mazzanti, 2012). Porter's view to EI (Porter, 2010) requires a full redefinition of the innovation diamond and firm strategy, taking into account the important role of complementarities and trade-offs between innovation practices (Antonioli et al., 2013). This sort of strategic thinking is even more relevant when dealing with more radical innovations such as those leading to CO_2 abatement, which require an integrated rethinking of technological and energy processes, in contrast to the use of end of pipe technologies to abate pollutants. This is part of the motivation behind the absence of an absolute decoupling between production and CO_2 in most OECD countries. A similar relevance in complementarity pertains to the design and introduction of policies which are coherently integrated within the environmental-energy realm and to the consideration of this alongside innovation and industrial policies.

Sectoral differences have gained considerable consideration since the Pavitt taxonomy was introduced into the economics of innovation: science-based, specialised suppliers, supplier dominated and scale intensive firms. This categorisation was based on sources and patterns of technological change. From a conceptual point of view, we mainly refer to the integrated concepts of sectoral and national systems of innovation, which have been consolidated into innovation-oriented evolutionary theory (Francis and Malerba, 2004) and have been exploited in environmental economics literature examining EI and policy (Crespi, 2013; Costantini and Mazzanti, 2012). Malerba promotes a sectoral system view of innovation. He stresses that sectors differ greatly with respect to their knowledge basis, technologies, production processes, policy and institutional environments, complementarity between innovations and market demand. Regarding policies, both within a strict innovation/industrial aspect and for what concerns an environmental aspect, these arguments matter. A 'one size fits all' approach may be not effective in supporting innovation diffusion and consequently economic and environmental performances. This is a hot-button issue in the EU, where 'mainstream economics' have probably influenced the implementation of policies that were constructed on the one-size-fits-all paradigm. The alternative is to shape policies according to sector and regional features following more bottom up and diversified approaches.

Along such conceptual lines of thought, Peneder (2010) analyses the differences between firm level studies and sector analyses: firms' heterogeneity is crucial, but differences between sectors and their regularities are also important. Sectors represent a crucial and unique 'place' where innovation is developed and diffused: "Industry characteristics matter and cannot be ignored […] in designing policy programs and tailor them more effectively to the needs of targeted firms" (Peneder, 2010). We may also refer to the consolidated paradigm of technological regimes developed early on by Malerba and Orsenigo (1997). They observe that technological regimes may be a fruitful concept in studying how innovative activities are organised differently and industries evolve over time. Of greater relevance here is their main finding that innovative activities are sector specific, insofar as the features of technological environments are common to groups of industries. They consequently find differences across sectors in the patterns of innovation and dynamic economic performance and similarities across countries. This is a key conceptual justification for studying sectors at various degrees of aggregation in a realm where innovation plays a major role in linking economic and environmental performance (Ambec and Lanoie, 2008; Jaffe and Palmer, 1997; Porter and van der Linde, 1995). According to Breschi (2000), this reasoning is not aimed at denying the relevance of national innovation systems but affirms that an analysis based on sectors maximises the possibility of effectively investigating the behaviour of agents in a dynamic innovative world (Costantini and Mazzanti, 2012; 2013).

As example of a general descriptive EU sector perspective on innovation, Table 1 exhibits the ranking of five main countries (Germany, France, Italy, Sweden, Netherlands, whose selection depended upon relevancy, heterogeneity, data availability) by their percentages of adoption of environmental innovation measures. To provide various insights, we sketch certain general economic categories and other more specific ones such as some key services, utility sectors that are important for managing natural resources, and heavy industrial sectors that are under the EU ETS policy aimed at cutting CO_2 emissions (potentially inducing innovation). If we look at the three main eco-innovation indicators mentioned above, it is clear that the leading EU countries are Germany and France. Italy shows the worst performance in most sectors, with the exception of some ETS sectors (manufacture of metal products, manufacture of paper, air transport) and a few service sectors (financial services, services for the business economy). Table 1 shows the anticipated dominance of Germany in EI adoption, which reflects the German leadership on invention (Dechezlepretre et al., 2011). German leadership is driven by the superiority of its core industrial sectors.

The evidence concerning services is more varied. Germany does not lead. France is on average the country presenting the best performance, with Sweden and Netherlands also appearing as leaders in some cases. In services that are more integrated with industry, Germany nevertheless appears to lead in some areas, thus showing the relevance of vertical integration. Though Italy presents a consistent gap concerning CO_2 innovation, its role is not negligible in technological waste disposal adoption, which indirectly relates to CO2 abatement. The role of packaging waste systems that have been effectively implemented by firms through schemes that fund recycling and recovery might be investigated in the future. A final look at 'utility'-related sectors shows that while German strength is plausibly confirmed in (highly regulated) areas such as waste management and collection, France acts as a major force as well. The gap between France and Italy in this field, where major utilities and public-private companies are important players in the production of mixed public services, deserves further investigation. The role of the (type of) 'decentralization' of public services (higher in Italy in general terms) and related policies is a possible key issue. Its relationship with environmental innovations has been overlooked.

This paper analyses the role of external effects in the adoption of EI, namely policy and sector integration. We take a EU scale by using the EU CIS data on innovation adoption. This limits the analysis to a cross section framework. We note that Large cross-section and longitudinal datasets are available for patents, namely invention. Our focus, however, is on the diffusion and adoption of eco-innovations. The most comprehensive dataset on eco-innovation is the CIS 2006-2008 by Eurostat. The sector data level covers EU27, while aggregated micro data covers only some countries[1].

Section 2 presents the data and the model. Section 3 presents the econometric evidence. Section 4 concludes.

[1] The quantitative analyses in section 6 make use of the most recent and only available data at the EU level for EI concerning CO2: (i) the Eurostat sector CIS data and the (ii) aggregated meso data (aggregation of similar firms into clusters) that are provided by Eurostat in the CIS Cd-rom. Option (i) is the best given the wide EU coverage, option (ii) is interesting since it extends dataset breadth. We rule out analyses on micro data from a methodological perspective. It would nevertheless be impossible to present full EU coverage due to national based data availability and copyright issues. The literature on EI at the micro level usually develops at the national level (Cainelli and Mazzanti, 2013; Horbach et al., 2012).

Table 1. Adoption of environmental innovation measures over 2006-2008. Ranking of five EU countries.

		leader CO_2 Innov	leader emissions innov	leader waste reduc inn
General	Manufacturing	Germany	Germany	Germany
General	All Core NACE activities related to innovation activities	Germany	Germany	Germany
General	Industry (except construction)	Germany	Germany	Germany
Services	Financial and insurance activities	Netherlands	France	France
Services	Financial service activities, except insurance and pension funding	France	France	France
Services	Services of the business economy	Sweden	France	France
Services	Innovation core service activities	Germany	Germany	France
Services	Insurance, reinsurance and pension funding, excluding compulsory social security	Sweden	Netherlands	France
ETS	Manufacture of basic metals	Germany	Germany	Germany
ETS	Manufacture of basic metals and metal products, excluding machinery and equipment	Germany	Germany	Germany
ETS	Manufacture of chemicals and chemical products	Germany	Germany	Germany
ETS	Manufacture of coke and refined petroleum products	Germany	Germany	Germany
ETS	Manufacture of metal products, excluding machinery and equipment	Germany	Germany	Germany
ETS	Manufacture of other non-metallic mineral products	Germany	Germany	France
ETS	Manufacture of paper and paper products	Germany	Germany	Germany
ETS	Air transport	Germany	Germany	France
Utility	Sewerage	France	Germany	Germany
Utility	Sewerage, waste management, remediation activities	Sweden	Germany	France
Utility	Waste collection, treatment and disposal activities; material recovery	Germany	Germany	France
Utility	Water collection, treatment and supply	Germany	France	France
Utility	Water supply; sewerage, waste management and remediation activities	Sweden	Germany	France

Source: CIS Data extracted from on line Eurostat database (May 2013).

2. Environmental policy and innovation: relevant literature

The link between environmental regulation and competitiveness has been the focus of economic debate for decades. Until twenty years ago, the economic discipline was dominated by the idea that any attempt conducted by environmental regulation in abating pollution would necessarily translate into an increase of internal costs for the compliant firm. In this framework of analysis, if there were profitable opportunities for reducing pollution, an optimizing firm would certainly have already adopted them. Moreover, many theoretical studies during the 1970s support the idea that a country's comparative advantage could have been affected in a negative manner by stringent environmental regulation. For instance, the works of Pethig (1975), Siebert (1977) and McGuire (1982), stress that environmental policies increasing firms' internal costs affect countries' competitiveness, decreasing exports, increasing imports, and lowering the country's general capacity to compete on an international market. Moreover, if production factors are free to move across countries, a more stringent environmental regulation in the long-run can produce movement of the manufacturing capacity from more regulated countries to less regulated ones (which are often called "Pollution Havens" in modern environmental and trade studies). In this view, command and control regulation for example, which restricts the choice of technologies or inputs in the production process, would increase the constraints a firm has to face, while taxes and tradable permits, charging for production by-products (waste or emissions) would generate costs that did not exist before regulation. Nevertheless, in the last two decades, many scholars have challenged this dominant idea. In particular, Porter and Van der Linde, in different contributions (1991, 1995), strongly criticised this approach, underlining that the consolidated paradigm was not considering all aspects of the environmental regulation/competitiveness relationship. Moving from the static approach in which technology was held constant to a dynamic context, the authors showed how in practice some of the loss of competitiveness related to environmental regulation was compensated by an increase in innovation driven by the policy itself. In the view of Porter and Van der Linde, a properly designed policy framework may place pressure on firms, pushing them to develop new innovations and promoting technological change. Within this view, the additional policy-driven innovation may offset the loss of competitiveness due to the additional costs of regulation. Porter and Van der Linde show how regulation can specifically act through 5 different channels (1995). First, regulation signals resource inefficiencies and potential technological improvements to companies; second, regulation focused on information gathering can achieve major benefits by raising corporate awareness; third, regulation reduces uncertainty in pollution-causing activities; fourth, by putting pressure on firm cost function, regulation motivates cost saving innovations; fifth, regulation makes free riding behaviour in the transition phase through an innovation-based equilibrium more difficult. Based on this seminal work, Jaffe and Palmer (1997) discerned the three different implications of the Porter Hypothesis, proposing a taxonomy which is helpful in distinguishing the different lines of research that have further developed. The first idea, also called the Narrow Porter Hypothesis, shows that certain types of environmental regulations are able to stimulate innovation, following the idea that policy design matters, and command and control policies are generally (with exceptions) less efficient than economic tools in promoting innovation and technical change. A second version of the Porter Hypothesis, called Weak, in synthesis states that a well-designed environmental regulatory system may stimulate certain kinds of innovation. Finally, the strongest version of the Porter Hypothesis holds that not only regulation is able to spur innovation, but also that this gain in efficiency is able to completely offset any loss in competitiveness due to compliance costs. In other terms, this last approach suggests that more stringent and well-designed regulation promotes competitiveness.

Porter's original idea has been strongly criticised, especially by Oates et al. (1995) who suggest that Porter's entire reasoning was based on wrong assumptions and was not compatible with the concept of profit maximizing in firms. However this is the same point Porter himself stressed. In his view, firms operate in a dynamic and uncertain framework, where the agent behaves following Simon's idea of bounded rationality. In such a context, the rational of firms depends on their managers, who might have different objectives with respect to the firm, or who do not have the competence required to innovate at an adequate level. Following this line of reasoning, some theoretical works have explained the Porter hypothesis as dependent on risk-adverse managers (Kennedy, 1994), those resistant to costly changes in their routines (Ambec and Barla, 2007), or those rationally bounded (Gabel and Sinclair-Desgagé, 1998). Ambec and Barla (2002), on the other hand, argue that whenever managers have privileged information as to the outcome of R&D investments and governments do not, a problem of asymmetric information may develop, from which managers may derive a rent. On the contrary, if a government enacts stringent environmental regulations, it can deprive managers of their advantage, overcoming this problem. Obviously, the possible presence of this inefficiency supports the presence of the Porter Hypothesis.

Beyond the theoretical contributions discussed above, the core debate around the Porter Hypothesis has been developed through many different empirical studies. Following the survey conducted by Ambec et. Al. (2013), these works can be divided into three different macro areas, representing three different connotations: weak, strong and narrow. This paper is in the first group.

As concerns the first group of works, referring conceptually (and often not explicitly) to the so-called "weak" version, one of the first contributions is Jaffe and Palmer (1997), which tests for the presence of a Porter hypothesis using pollution abatement expenditure as a proxy for environmental regulation, and the total firm R&D expenditure along with the total number of patent applications as a proxy for innovation in a panel of U.S. manufacturing industries over the 1973-1991 period. Their findings support the idea that compliance expenditure has a positive and significant effect on innovation measured as R&D, while they do not find significant results in patent related specifications. This last unexpected result may be due to the nature of the dependent variable: the authors use total patent counts, instead of using environmentally-related ones. In another work along these lines, Brunnermeier and Cohen (2003) use U.S. manufacturing industry data and empirically analyse the determinants of environmental technological innovation, using the number of environmental patent applications as the innovation proxy, and both pollution abatement expenditures and the number of air and water pollution control inspections as proxies for regulation. They find a significant impact of the first variable, and an insignificant impact of the second one. Among other covariates, they find that international competition stimulates environmental innovation. A larger effect is found by Carrion-Flores and Innes (2010) using U.S. sectoral data, even though the effect on long-term emission reduction induced by innovation is small. Another work on patent data at the firm level is that of Popp (2003), which by analysing 186 plants in the U.S. from 1972-97 finds that the tradable permit scheme for the reduction of SO2 has been able to promote technical changes, increasing SO2 removal efficiency and decreasing operation and removal costs. As for cross-country studies, De Vries and Withagen (2005) study the effect of SO2 environmental regulation on national patent counts in relative technological classes, finding some evidence of a link between policy stringency and environmental innovation. A second, more recent example of a pertinent cross-country study is that of Johnstone et. al. (2010), who address the effect of many different policy tools on the innovative performance of the main renewable technologies (Solar, Wind, Geothermal, Ocean, Biomass and Waste) in 15 OECD countries over the 1978-2003period. They find general strong evidence of a Porter hypothesis. In most of their specifications, different policy tools are positively and significantly related to technological change, and more interestingly, they discerned the effect of different policy designs on different technologies. Subsidies and feed-in tariffs are, for example, more suitable for inducing innovation on more costly technologies like solar power, while tradable certificates show a stronger effect on technologies that are closely competitive with fossil fuels, such as wind power. Kneller and Manderson (2012), analyse 25 UK manufacturing industries over the 2000-2006 period and consider the role played by expenditure on pollution control in affecting innovation measured with environmental R&D. They find that the effect is positive as environmental R&D may crowd out other types of R&D investments.

Johnstone et al. (2012) carry out an analysis using both an unbalanced panel of 77 countries over the years 2001 and 2007 and using data from the European Patent Office (EPO) World Patent Statistical (PATSTAT) database and the World Economic Forum's (WEF) 'Executive Opinion Survey'. They use a cross-country dataset, and find that higher environmental stringency positively affects environmental innovation. Finally, Nicolli and Mazzanti (2011) study the effect of environmental policies on innovation in the specific waste streams of paper and plastic packaging waste, end-of-life vehicles, composting, and on aggregate waste for OECD countries from 1970 to 2007. They find two important results: first, specific waste stream regulation does seem to play an important role in the promotion and diffusion of innovation. Second, they outline how the waste sector seems to have reached a degree of technological maturity, and how it is now experiencing a decreasing trend in patenting activities. These results seem to suggest that there have been two different policy eras in the case of waste in OECD countries, a first and older wave of policies (at the end of the 1980s and beginning of the 1990s) that produced a technological shock in the system, and a second, more recent wave of policy, which seems to have had less impact on environmental innovation.

The second strand of literature reflects the "strong" version of the Porter Hypothesis, i.e. it is devoted to testing whether there is a link between environmental regulation and competitiveness of the firms. For A review of this literature we refer to Jaffe et al. (1995), Berman and Bui (2001) and by Lanoie et al. (2008) and Costantini and Mazzanti (2012).

We aim at providing new evidence on the weak version of the PH – broadly conceived - in this paper by taking a sector based view that also looks at the upstream and downstream sector integration. A similar sector based approach that integrates innovation, policy and environmental data[2] is used in Costantini and Mazzanti (2012), Marin and Mazzanti (2013), who nevertheless primarily look at the strong version of the PH storyline.

The Main research hypotheses that derive from the analysis of the past literature are the following:

H1 – Whether the stringency of environmental regulations[3] is correlated to higher EI adoption in EU sectors. We test H1 in relation to the economy as a whole and industry sectors only.

H2 – Whether the stringency of environmental regulations mediated by downstream and upstream sector integration (Upstream and downstream emission intensity measures) is correlated to higher EI adoption in EU sectors. We test H2 in relation to the economy as a whole and industry sectors only.

We thus originally test a 'direct' and 'indirect' effect of regulations, by integrating innovation and environmentally extended input output data (Marin et al., 2012).

[2] We note that the sector level is the only feasible to provide a EU wide evidence. In fact, the firm based analysis is constrained by data availability: Innovation CIS data are mostly available to researchers only at national level. Even relaxing this constraint, there is no possibility to match innovation and emission / value added data at the moment: micro data are protected by privacy policies and emissions data are rarely available, excluding niche case studies and specific sectors in specific countries. In addition, even emission data are often 'protected' and not fully available to researchers.

[3] Captured by the CO2/value indicator as usual in the literature, see Costantini and Crespi (2008).

3. Empirical framework

3.1 The data

Our main aim is to investigate the extent to which climate change and energy policies (exemplified by various indicators of environmental regulatory stringency) affect the propensity of European sectors to adopt eco-innovations aimed at reducing CO2 emissions. In this section, we again use a full sectoral level perspective by exploiting the detailed information offered by the CIS2008, the only currently available source on eco-innovation adoption with overall EU coverage.

In addition to this assessment of the policy-induced hypothesis, we enrich the econometric analysis in two additional ways which touch upon the role of external sources of innovation. On the one hand we address the role of services, namely the role of industry-service integration as a driver (or hindering effect) of eco-innovations (Cainelli and Mazzanti, 2013, EEA, 2013; Gilli et al., 2013). We exploit EU input-output tables – integrated with coherent CIS sector data - to analyse the role of (vertical) integration as a source of eco-innovation adoption. Increasing inter-sectoral integration is to be taken into account and might play a role in explaining the current adoption of EI.

We present evidence on the basis of the primary source of sector CIS data which offers full EU coverage (available for free download). We use CIS2008 at the country and sectoral levels (Eurostat) and we further merge this data with CO2 air emissions and value added by sectors for the year 2005 from the Eurostat NAMEA (National Accounting Matrix including Environmental Accounts[4]) and with the EU27 input-output table for year 2008 (Eurostat)[5]. We end up with 448 observations for 16 EU countries[6] and 43 sectors (23 industrial sectors and 20 service sectors)[7].

The CIS2008 is a unique source of information on the eco-innovative behaviours of European firms, covering the 2006-2008period. For the purposes of our analysis, we use information on the adoption of eco-innovations aimed at reducing CO2 emissions and on self-reported motivations for eco-innovation (of any kind). Moreover, we use some standard control variables related to R&D, cooperation and adoption of other innovations (product or process) that are common to the literature on eco-innovation drivers (Horbach et al., 2012; Cainelli et al., 2012; Kemp and Pontoglio, 2012, Ghisetti and Quatraro, 2013). A detailed description of the variables is reported in Tables 10-13.

The CO2 emission intensities of sectors are employed as proxies of environmental regulatory stringency. CO2 emissions and value added, in current euros, are retrieved from the NAMEA (National Accounting Matrix including Environmental Accounts) collected by Eurostat for the year 2005. While the CIS2008 uses the Nace rev. 2 as sectoral classification, no information on emissions was available with a Nace rev. 2 classification prior to 2008. For this reason, we reclassified CO2 emissions by Nace rev 1.1 sectors for 2005 to the Nace rev 2 classification.

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[4] On NAMEA innovation and economic related issues, we refer to Costantini et al., (2012). We use 2005 to define a lag with respect to 2006-2008 (mitigating simultaneity and endogeneity) and due to data availability concerns.

[5] A similar approach has been used in Crespi (2013).

[6] Belgium (BE), the Czech Republic (CZ), Germany (DE), Estonia (EE), Finland (FI), France (FR), Hungary (HU), Ireland (IE), Italy (IT), Lithuania (LT), the Netherlands (NL), Poland (PL), Portugal (PT), Romania (RO), Sweden (SE), Slovakia (SK).

[7] Because of missing information about either emission data or CIS data, our potential sample of 688 observations is reduced to 448.

The main limitation of the present analysis relate to the policy variable chosen. Nevertheless, the currently limited availability of energy and environmental taxation data at the sector level prevents analyses that use specific policy proxies. The use of measure based on the consumption of goods as proxy of environmental policies is, however, a very common approach in empirical literature. Damania et al., (2003), for instance, used grams of lead content per gallon of gasoline, while Fredriksson and Vollebergh (2009) used energy intensity, defined as aggregated physical energy units per unit of value added (tons of oil-equivalent per dollar). The idea behind this approach is that both measures are highly correlated with the latent environmental policies. Energy efficiency has been, for instance, the focus of many energy and environmental policies over recent decades, equally lead emission, being a harmful air pollutant has been the target of many environmental policies over the last 25 years[8]. Moreover, Damania et al., (2003) shows that these measures are generally highly correlated with other commonly used measures of environmental policy stringency. Our case is not different. If from the one hand is reasonable to assume that a lower CO2/VA share is the output of stringent environmental policies. In particular, CO2 intensity could be correlated with non-measured energy intensity, which could produce a bias in the estimation if this omitted variable is also correlated with the dependent variable. Given this concern, this variable can only be considered as a proxy of the latent stringency.

In order to investigate the extent to which environmental regulation drives eco-innovation aimed at reducing CO2 emissions, we use a cross-sectional regression analysis in which the dependent variable, the share of firms in the sector and country which have adopted eco-innovations (EI_CO2), is explained by a series of covariates. We apply a linear econometric model (STATA software) in which we include, in addition to our 'policy' variables, a series of controls as well as sector and country dummies to account for unobserved differences in the propensity to eco-innovate by country and sector. Regarding integration between sectors, CO2 emission intensities of upstream and downstream sectors are employed as proxies of environmental regulatory stringency. CO2 emissions and value added, in euros, are retrieved from the NAMEA (National Accounting Matrix including Environmental Accounts) collected by Eurostat for the year 2005. While the CIS2008 uses the Nace rev. 2 as sectoral classification, no information on emissions was available with a Nace rev. 2 classification prior to 2008. For this reason, we reclassified CO2 emissions by Nace rev 1.1 sectors for 2005 to the Nace rev 2 classification. Upstream and downstream emission intensity measures have been estimated by weighting emission intensity of other sectors with the EU27 input-output table for 2008. Due to the limited availability of country-level input-output tables based on the Nace rev. 2 classification, we decided to use the European table for all countries. As stated, the first table available is the one for 2008. Upstream emission intensity reflects the emission intensity of suppliers of a sector weighted by the share of intermediate input for each supplying sector. Downstream emission intensity uses as weights the share of output sold to downstream sectors as intermediate inputs.

[8] This approach has many advantages. First, data are readily available and of good quality; second, they provide a direct and easy to interpret measure of stringency; third, they are generally available for long time series which allow to have both within-country and between-country variation. Such measures of policy stringency might, however, be bias if part of the variation of the indicator is due to factors different from the policy itself. If, for instance, the variations in the series of energy intensity data depend on an unobserved characteristic, which does not relate to the real policy stringency, the result would be either an overestimation or an underestimation of the effect of the policy.

The cross-sectional nature of this data limits the possibility to interpret estimates in a causal way, due to the possible presence of unobserved heterogeneity and reverse causality. Moreover, we could not find any reasonable and available instrumental variable for our policy variables. Due to these caveats, results should be interpreted in terms of conditional correlations.

Before commenting on the results of our econometric analysis, some descriptive evidence merits discussion. Table 2 reports the correlation matrix among our variables of interest, and Table 3-4 some preliminary descriptive statistics. First, we observe some strong (unconditional) correlations among our variables of interest. The correlation regarding the motivation behind eco-innovation (existing and expected regulations, market demand and voluntary codes) is positive and in most cases above 50 percent.

3.2 Econometric evidence

3.2.1 Policy effects

The results for various specifications of the relationship between environmental regulation and eco-innovation are reported in Table 5. We estimate en extended innovation function that contains policy effects (Horbach et al., 2012; Horbach, 2008; Crespi, 2013). OLS is the estimation procedure, corrected for heteroskedasticty.

We report results for a sub-sample of industrial sectors (from letter B to letter F of the Nace rev. 2 classification) as well as for the full sample of sectors (H1). We observe little influence of our control variables, besides the strong positive effect of average firm size, as drivers of eco-innovation. Engagement in R&D is never significant while cooperation is sometimes positive and weakly significant for industry and process-or-product innovation is negative and weakly significant, here as well for industry only.

In columns 1 and 4 of **Errore. L'origine riferimento non è stata trovata.**4 we observe a strong positive effect of expected regulation and market demand as drivers of the adoption of eco-innovation to reduce CO2 emissions, while no effect is found for existing regulation and voluntary codes. The absence of effect for existing regulation is not so surprising, given the absence of ambitious limits during the 2006-2008 period. European firms seem more concerned by future policies, such as the first and second phase of the EU ETS and other possible policies aimed at achieving the ambitious targets set by the EU in terms of CO2 emission reduction[9]. Finally, due to the good nature of the public benefit deriving from the adoption of eco-innovations reducing CO2 emissions, the presence of a market demand for low carbon goods and services is a strong incentive for firms to adopt eco-innovations in this field. These results appear to be very similar for the two considered samples.

In column 2 and 5 of Tab. 5 we only include past CO2 emission intensity as an indicator of policy stringency. Emission intensive sectors and countries are more likely to attract the attention of policy makers and are most likely to be required to pay relatively more environmental taxes (if any) per unit of monetary output than other less emission-intensive sectors. This assumption is somewhat confirmed by the strong correlation between emission intensity and 'existing' and 'expected'

[9] The EU 2020 package sets the target of cutting GHG emissions by 20 percent from the 1990 level by 2020 while the 'Roadmap for moving to a competitive low-carbon economy' aims at abating 80 percent of GHG emissions by 2050.

regulation as reported by firms (a correlation of about 44 percent in both cases). In our regression framework, we observe that more emission intensive sectors and countries are more likely to adopt CO_2-related eco-innovations[10].

Table 2 - Description of the variables

Variable	Description
% EI_CO2	Share of firms which introduced at least one eco-innovation with an environmental benefit "reduced CO2 footprint (total CO2 production) by your enterprise"
Existing regulations	Share of firms which introduced environmental innovations (of any kind) in response to "existing environmental regulations or taxes on pollution"
Expected regulations	Share of firms which introduced environmental innovations (of any kind) in response to "environmental regulations or taxes that you expected to be introduced in the future"
Market demand	Share of firms which introduced environmental innovations (of any kind) in response to "current or expected market demand from your customers for environmental innovations"
Voluntary codes	Share of firms which introduced environmental innovations (of any kind) in response to "voluntary codes or agreements for environmental good practice within your sector"
log(CO2/VA)	Logarithm of sectoral CO2 emissions per value added (year 2005)
log(upstr_emiss)	Logarithm of CO2 emission intensity per value added by upstream sectors (weights from EU27 input-output table for 2008)
log(downstr_emiss)	Logarithm of CO2 emission intensity per value added by downstream sectors (weights from EU27 input-output table for 2008)
% has R&D	Share of firms which carried out R&D expenditure
% cooperate	Share of firms which cooperate on innovation activities with other enterprises or institutions
% prod or proc	Share of firms which introduced product or process innovations
log average size	Logarithm of average firm size in the sector (in terms of employees)

Table 3 – Correlation matrix

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
% EI_CO2	(1)	1	0.25	0.32	0.35	0.38	0.34	0.08	0.16	0.01	0.07	0.18	0.24
Existing regulations	(2)		1	0.85	0.47	0.57	0.44	0.31	0.42	-0.14	0.05	-0.15	0.19
Expected regulations	(3)			1	0.55	0.60	0.44	0.33	0.42	-0.05	0.11	-0.11	0.18
Market demand	(4)				1	0.61	0.14	0.05	0.14	0.16	0.22	0.03	0.15
Voluntary codes	(5)					1	0.21	0.07	0.18	0.06	0.23	0.08	0.16
log(CO2/VA)	(6)						1	0.51	0.61	-0.14	0.02	-0.06	0.23
log(upstr_emiss)	(7)							1	0.80	-0.23	-0.07	-0.24	0.01
log(downstr_emiss)	(8)								1	-0.26	-0.01	-0.20	0.03
% has R&D	(9)									1	0.59	0.52	0.26
% cooperate	(10)										1	0.66	0.42
% prod or proc	(11)											1	0.30
log average size	(12)												1

[10] The currently limited availability of energy and environmental taxation data at the sector level prevents analyses that use specific policy proxies. CO2/VA is a generally widespread proxy of stringency.

Table 4 - Descriptive statistics ('environmental' variables; averages weighted by the number of firms)

Country	% EI_CO2	Existing regul	Expected regul	Market demand	Voluntary codes	CO2/VA	Upstr emiss	Downstr emiss
BE	28%	21%	17%	14%	27%	0.61	1.31	0.37
CZ	17%	43%	28%	16%	25%	0.59	1.9	0.56
DE	37%	19%	18%	17%	18%	0.35	0.97	0.31
EE	13%	27%	21%	18%	28%	1.49	3.39	1.38
FI	25%	17%	20%	32%	30%	0.48	1.05	0.35
FR	21%	23%	14%	19%	27%	0.22	0.66	0.18
HU	19%	44%	38%	35%	37%	0.61	1.31	0.39
IE	33%	29%	21%	26%	31%	0.51	1	0.41
IT	15%	25%	18%	14%	16%	0.4	0.73	0.26
LT	18%	41%	34%	27%	26%	0.57	3.61	0.96
NL	14%	9%	8%	12%	11%	0.21	1.23	0.27
PL	20%	28%	19%	14%	14%	1.9	3.03	1.18
PT	32%	32%	18%	21%	41%	0.74	1.33	0.43
RO	20%	37%	20%	17%	17%	1.22	2.33	0.88
SE	28%	8%	14%	15%	15%	0.34	0.69	0.27
SK	11%	41%	31%	14%	20%	0.87	2.7	0.68
Sector	% EI_CO2	Existing regul	Expected regul	Market demand	Voluntary codes	CO2/VA	Upstr emiss	Downstr emiss
B	31%	35%	28%	14%	31%	5.38	3.01	3.39
C10-C12	28%	26%	20%	13%	21%	0.46	0.55	0.16
C13-C15	13%	19%	12%	10%	15%	0.33	0.27	0.17
C16-C18	24%	26%	20%	20%	21%	0.4	0.34	0.4
C19-C23	25%	31%	25%	22%	22%	1.79	1.06	0.65
C24-C25	25%	25%	18%	16%	19%	0.63	1.17	0.52
C26-C30	23%	30%	22%	21%	23%	0.17	0.4	0.19
C31-C33	18%	22%	16%	14%	17%	0.37	1.19	0.45
D	47%	43%	39%	23%	28%	12.97	8.84	3.87
E	35%	48%	37%	26%	37%	3.05	1.27	1.15
F	20%	31%	22%	27%	26%	0.08	0.81	0.1
G	21%	25%	15%	16%	21%	0.08	2	0.33
H	42%	29%	26%	15%	22%	0.89	2.11	0.67
I	17%	15%	13%	12%	26%	0.1	0.21	0.05
J	10%	8%	5%	9%	10%	0.07	1.3	0.23
K	14%	11%	8%	11%	14%	0.02	0.44	0.14
L	19%	23%	16%	18%	26%	0	0.57	0.07
M	16%	11%	9%	13%	15%	0.04	0.71	0.32
N	13%	11%	7%	12%	16%	0.08	3.09	0.49
Total	**23%**	**24%**	**18%**	**17%**	**21%**	**0.49**	**1.17**	**0.38**

3.2.2 sector integration: Upstream and downstream policy effects

We then analyse the external sources of innovation, primarily represented by suppliers of intermediate inputs (H2). In Table 6 we wish to illustrate the extent to which eco-innovation behaviour is influenced by the average emission intensity of upstream sectors (i.e. suppliers of intermediate inputs).

Upstream and downstream emission intensity measures have been estimated by weighting the emission intensity of other sectors with the EU27 input-output table for 2008. Upstream emission intensity reflects the emission intensity of suppliers for a sector weighted by the share of intermediate input for each supplying sector. Downstream emission intensity uses as weights the share of output sold to downstream sectors as intermediate inputs.

In Table 6, it is of particular interest that the way in which the question about CO2-related eco-innovations is formulated in the CIS2008 suggests to firms to consider emissions along the whole supply chain (footprint). Sectors with more emission intensive upstream partners are thus required to eco-innovate more than other sectors in order to reduce their CO2 footprint. This is the case according to our estimates. The positive and significant effect of upstream emission intensity (columns 1 and 4) is actually stronger in statistical significance and magnitude than the effect of 'direct' CO2 emission intensity (columns 2 and 5). However, when also including self-reported drivers of eco-innovation, the effect of both direct and upstream emission intensity is no longer significant.

Finally, in Table 7 we look at downstream emission intensity as a driver of eco-innovation (H2). Considering a 'CO2 footprint' in the broadest way would require downstream emission intensity to be taken into account by firms ('from the cradle to the grave' approach). There is some evidence of downstream CO2 intensity to stimulate eco-innovation aimed at abating CO2 (columns 1 and 4), even though the effect is not robust to the inclusion of direct CO2 emission intensity and self-reported policy drivers.

Table 5 - Econometric results – direct emission intensity only

Dep: % EI_CO2	Industry			All sectors		
	(1)	(2)	(3)	(4)	(5)	(6)
% cooperate in	0.0416	0.158*	0.0490	-0.0293	0.0677	-0.0279
innovation activities	(0.0924)	(0.0808)	(0.0932)	(0.0709)	(0.0627)	(0.0711)
% has R&D	0.00383	-0.00450	-0.00302	0.0347	0.0517	0.0349
	(0.0482)	(0.0543)	(0.0477)	(0.0336)	(0.0388)	(0.0335)
% has product or	-0.0737	-0.149**	-0.0836	-0.0181	-0.0831	-0.0244
process innovation	(0.0715)	(0.0730)	(0.0717)	(0.0555)	(0.0589)	(0.0562)
log average size	0.0183*	0.0229**	0.0173*	0.00695	0.0158*	0.00648
(employees)	(0.0101)	(0.0109)	(0.0102)	(0.00851)	(0.00933)	(0.00842)
Existing regulations	-0.0782		-0.0788	-0.0184		-0.0159
or taxes	(0.0836)		(0.0824)	(0.0727)		(0.0720)
Expected regulations	0.281***		0.262***	0.268***		0.251***
or taxes	(0.0861)		(0.0855)	(0.0770)		(0.0772)
Market demand	0.169**		0.168**	0.178***		0.179***
	(0.0697)		(0.0699)	(0.0607)		(0.0611)
Voluntary codes	0.111		0.114	0.135**		0.139**
	(0.0749)		(0.0739)	(0.0619)		(0.0617)
log(CO2/VA)		0.0133***	0.00668		0.0113***	0.00509
		(0.00507)	(0.00477)		(0.00438)	(0.00411)
Constant	0.210***	0.317***	0.228***	0.189***	0.289***	0.198***
	(0.0544)	(0.0573)	(0.0571)	(0.0466)	(0.0478)	(0.0475)
N	312	312	312	448	448	448
R2	0.618	0.545	0.621	0.648	0.561	0.649
F	15.15	12.55	15.02	21.41	18.29	21.00
Test country dummies	15.18***	14.36***	15.51***	14.89***	15.19***	15.03***
Test sector dummies	2.792***	4.365***	1.996**	4.186***	8.322***	2.517***

OLS estimates. Robust standard errors in parenthesis. * p<.1, ** p<.05, ***p<.01

Table 6 - Econometric results – direct and upstream emission intensity

Dep: % EI_CO2	Industry			All sectors		
	(1)	(2)	(3)	(4)	(5)	(6)
% cooperate in	0.149**	0.152**	0.0489	0.0737	0.0721	-0.0271
innovation activities	(0.0754)	(0.0772)	(0.0935)	(0.0600)	(0.0609)	(0.0713)
% has R&D	-0.00629	-0.00920	-0.00295	0.0455	0.0465	0.0345
	(0.0542)	(0.0537)	(0.0478)	(0.0384)	(0.0386)	(0.0335)
% has product or	-0.119*	-0.126*	-0.0839	-0.0686	-0.0763	-0.0238
process innovation	(0.0718)	(0.0729)	(0.0722)	(0.0576)	(0.0586)	(0.0563)
log average size	0.0255**	0.0245**	0.0172*	0.0177*	0.0168*	0.00661
(employees)	(0.0103)	(0.0106)	(0.0101)	(0.00911)	(0.00912)	(0.00833)
log(upstr emiss)	0.0311***	0.0259**	-0.000455	0.0211***	0.0158**	0.00165
	(0.00942)	(0.0103)	(0.00942)	(0.00767)	(0.00788)	(0.00677)
log(CO2/VA)		0.00492	0.00681		0.00710	0.00468
		(0.00551)	(0.00509)		(0.00450)	(0.00412)
Existing regulations			-0.0792			-0.0148
or taxes			(0.0840)			(0.0725)
Expected regulations			0.262***			0.249***
or taxes			(0.0870)			(0.0780)
Market demand			0.169**			0.178***
			(0.0710)			(0.0616)
Voluntary codes			0.114			0.139**
			(0.0740)			(0.0619)
Constant	0.269***	0.283***	0.229***	0.258***	0.272***	0.196***
	(0.0531)	(0.0558)	(0.0577)	(0.0452)	(0.0465)	(0.0476)
N	312	312	312	448	448	448
R2	0.555	0.556	0.621	0.563	0.566	0.649
F	13.82	13.76	14.55	19.08	18.33	20.61
Test country dummies	15.85***	15.32***	15.19***	15.66***	15.7***	15.04***
Test sector dummies	3.423***	3.39***	1.814*	14.64***	8.582***	2.505***

OLS estimates. Robust standard errors in parenthesis. * p<.1, ** p<.05, ***p<.01

Table 7 - Econometric results – direct and downstream emission intensity

Dep: % EI_CO2	Industry			All sectors		
	(1)	(2)	(3)	(4)	(5)	(6)
% cooperate in	0.148*	0.154*	0.0490	0.0677	0.0675	-0.0277
innovation activities	(0.0756)	(0.0789)	(0.0932)	(0.0605)	(0.0615)	(0.0711)
% has R&D	0.00203	-0.00573	-0.00312	0.0471	0.0481	0.0346
	(0.0548)	(0.0539)	(0.0478)	(0.0386)	(0.0388)	(0.0336)
% has product or	-0.121*	-0.136*	-0.0829	-0.0713	-0.0798	-0.0240
process innovation	(0.0731)	(0.0741)	(0.0726)	(0.0577)	(0.0587)	(0.0563)
log average size	0.0254**	0.0236**	0.0173*	0.0177*	0.0166*	0.00658
(employees)	(0.0106)	(0.0108)	(0.0102)	(0.00938)	(0.00932)	(0.00840)
log(downstr emiss)	0.0294**	0.0186	0.00112	0.0255**	0.0168	0.00174
	(0.0122)	(0.0130)	(0.0113)	(0.0109)	(0.0112)	(0.00955)
log(CO2/VA)		0.00940*	0.00646		0.00855*	0.00481
		(0.00540)	(0.00508)		(0.00453)	(0.00423)
Existing regulations			-0.0784			-0.0154
or taxes			(0.0831)			(0.0724)
Expected regulations			0.261***			0.250***
or taxes			(0.0858)			(0.0775)
Market demand			0.167**			0.178***
			(0.0700)			(0.0615)
Voluntary codes			0.113			0.138**
			(0.0741)			(0.0619)
Constant	0.263***	0.293***	0.227***	0.253***	0.272***	0.196***
	(0.0544)	(0.0586)	(0.0594)	(0.0469)	(0.0487)	(0.0491)
N	312	312	312	448	448	448
r2	0.544	0.549	0.621	0.560	0.564	0.649
F	13.66	13.54	14.64	19.08	18.38	20.49
Test country dummies	15.73***	15.39***	15.17***	15.81***	15.90***	15.06***
Test sector dummies	3.675***	3.542***	1.929**	12.39***	8.226***	2.501***

OLS estimates. Robust standard errors in parenthesis. * p<.1, ** p<.05, ***p<.01

4. Conclusions

The paper aimed at providing EU wide evidence on the role played by external sources of innovation, namely policy effects and market effects related to value chain integration. Sector based quantitative analysis presents various insights on the effects of environmental policy and other external drivers of EI, both taking upstream and downstream perspectives. We have originally integrated EU CIS data with NAMEA and Input output datasets.

We do observe a strong positive effect of *expected* regulation and market demand as drivers of the adoption of eco-innovation to reduce CO2 emissions, while existing regulations do not influence adoption. This might call the current stringency and effects of EU policies into question and enhance the power of expectations and policy credibility for future achievements. By using past CO2 emission intensity (CO2 on value) as a proxy of policy stringency, we also find that emission intensive sectors are more likely to adopt CO2-related eco-innovations. The aforementioned results are valid for both the economy as a whole and for industrial sectors specifically.

We additionally show that not only environmental policies are important to sustain EI adoptions. Other 'external' drivers play a role. Looking at the role of inter sector integration and knowledge sources, we observe that sectors with more emission intensive upstream 'partners' eco-innovate more to reduce their CO2 footprints. The positive and significant effect of upstream emission intensity (supplier's emission intensity) is actually stronger than the effect of 'direct' CO2 emission intensity (policy effect).

The overall 'policy and institutional' environment is crucial, since EI is also strongly driven by the type and intensity of relationships with other sectors (which supply intermediate goods and 'knowledge'). This is increasingly relevant given the sector integration of the EU economy. Even if the main aim of environmental policy packages is to address market failures in the form of negative externalities, integrating considerations on the dynamic efficiency of tools (namely innovation effects) should be designed around a diversified set of issues and considerations which characterise the 'innovation environment'.

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