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On the green and innovative side of trade competitiveness? The impact of environmental policies and innovation on EU exports

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ABSTRACT

This paper aims at exploring how the export competitiveness of the European Union has been affected by environmental regulation and innovation. Starting from the Porter idea that environmental policies may foster international competitiveness by inducing technological innovation. We test both the strong and narrowly strong versions of the Porter hypothesis, in order to understand if such a virtuous cycle is confined into the environmental goods sector (respecting the narrow criterion) or it spreads out through the whole economic system. For this purpose we adopt a theoretically based gravity model applied to the export dynamics of five aggregated manufacturing sectors classified by their technological or environmental content.

When testing the strong version, the overall effect of environmental policies does not seem to be harmful for export competitiveness of the manufacturing sector, whereas specific energy tax policies and innovation efforts positively influence export flows dynamics, revealing a Porter-like mechanism. When testing the narrowly strong version, environmental policies, but more incisively environmental innovation efforts, foster green exports. These results show that public policies and private innovation patterns both trigger higher efficiency in the production process through various complementarity mechanisms, thus turning the perception of environmental protection actions as a production cost into a net benefit.

1. Introduction

The competitiveness and productivity performance of economic systems is a key factor in both economic development and environmental sustainability achievements. This paper deals with policy and innovation driven competitiveness performance in the European Union (EU), with a focus on export dynamics, by bringing together different streams of research. From a conceptual point of view, it matches together the consolidated realms related to the Porter hypotheses (Jaffe et al., 1995; Jaffe and Palmer, 1997; Porter and van der Linde, 1995) and the neo Schumpeterian conceptual framework of technological regimes applied to economic sectors (Breschi et al., 2000; Malerba and Orsenigo, 1997). This integration is in our eyes extremely fruitful given the centrality of the dynamic properties of innovative processes and structural change of economies that are present, not always in explicit forms, in the Porter hypotheses literature.

On a more specific level, the aforementioned perspective is engraved in the wider analysis of the relationship between economic and environmental performance, wherein the relevance of both innovation and environmental policy is crucial to decreasing the use of natural resources. Over dynamic scenarios, joint productivity gains can characterise economic systems, by mitigating or totally compensating the trade off between environmental and economic targets (Mazzanti and Zoboli, 2009). Increasing decoupling of environmental performance with respect to growth depends on scale, composition, technological and trade effects (Levinson, 2010) and on the inducement effect produced by the environmental policy mix on the innovation path (Hemmelskamp, 1997; Hemmelskamp and Leone, 1998; Requate, 2005; Requate and Unold, 2003; Roediger-Schluga, 2004). This inducement effect is also influenced by institutional, economic, trade and policy frameworks which contribute to the creation and diffusion of leading innovations (Rennings and Smidt, 2008) as well as by the timing of innovation adoption and the relative coherence of the regulatory framework with the overall economic system.

Narrowing down the focus, the effect of stringent environmental policy on economic competitiveness is a key point in the rich

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discussion on the effects of an Environmental Tax Reform (ETR), and the related potential double economic-environmental dividends (Andersen et al., 2007; Bosquet, 2000). The capacity of environmental policies to reinforce international competitiveness and resource efficiency, as claimed by the recent revision of the Lisbon Agenda, is even more relevant when the logic on how to move towards new growth scenarios in the current crisis assigns a key role to environmental sustainability. The years 2009–2011 are witnessing the implementation of recovery packages aimed at reassessing economic growth while improving sustainability (Bowen et al., 2009; Edenhofer and Stern, 2009). The greening of economic performance and exports may lead to new and greener structural competitive advantages. However, it needs to be supported by coevolving innovation and environmental policy instruments in the transition towards sustainable pathways (Geels and Schot, 2007).

To some extent, the EU has historically been a leader in the design and adoption of stringent environmental policies and many fears have arisen about the potential negative effects of such unilateral production constraints. Nevertheless, Andersen and Ekins (2009) recently surveyed EU experiences and scrutinized various cases where the implementation of carbon taxes and auctioned permits in the EU has been a fruitful way to reconcile environmental and economic performance. ETR has the potential to be shaped with a proper competitiveness target perspective, if well designed. Accordingly, Barker et al. (2007) and Pollitt and Junankar (2009) provide evidence discarding fears of potential negative effects associated with ETR and climate actions on employment, income distribution, economic growth and export performance.[1]

The themes discussed above lead directly to the potential win–win effects generated by properly designed environmental regulation instruments which help improving both efficiency and product values (Porter, 1991; Porter and van der Linde, 1995; Wagner, 2006). According to this reasoning, economic and environmental performance may go hand in hand without the conflicts generally prescribed by certain neoclassic frameworks.

It is worth noting that all aforementioned issues also touch the relationships between international trade and related environmental effects (Managi et al., 2009) which attracted attention in the 1970s after the oil crisis and witnessed a revival in the 1990s, when environmental policy and trade openness were increasing their pace (Chichilnisky, 1994; Rauscher, 1997). In particular, when the focus is on specific effects generated by environmental regulation on comparative advantages, the two prevailing perspectives are the pollution haven hypothesis (PHH) and the already mentioned Porter hypothesis (PH). As far as the PHH is considered, environmental policy enters a Heckscher–Ohlin theoretical framework as a constraint to factor endowment. Thus, the introduction of more stringent environmental regulations is potentially harmful to international competitiveness of domestic firms facing higher productive costs, leading to delocalization of dirty industries towards countries with a relatively lower burden of environmental regulation (Copeland and Taylor, 2004; Letchumanan and Kodama, 2000; Levinson, 2010; Muradian et al., 2002).

On the contrary, the PH assumes a more comprehensive and dynamic point of view, as the combination of environmental policies with private and public innovation strategies may lead to increasing environmental efficiency combined with productivity gains, if public policies are well-designed in stimulating proper techno-organizational innovation patterns. To this purpose, van den Bergh et al. (2000) stress that "adding a temporal dimension, the question can be raised of which types of behaviour [. . .] tend to survive under certain policies. This would provide information on the long run stability of environmental policy" (van den Bergh et al., 2000, p. 59).

The aforementioned strands of literature on the effects of environmental policies seem to find a better theoretical framework in the PH rather than in a PHH realm. Hence, this paper's main research question is whether environmental policies in the EU have undermined or created win–win opportunities for the competitiveness of its sectors. More precisely, it aims at focusing on the effects of combined environmental taxation and innovation dimensions on competitive advantages of manufacturing exports by using a theoretically based gravity model for trade analysis.

The rest of the paper is structured as follows: Section 2 provides a literature review on the Porter hypothesis and connected innovation oriented streams of literature and draws out the specific research hypotheses. Section 3 presents theoretical and methodological issues of the gravity model, while Section 4 gives details on the empirical model and the dataset. Section 5 comments on results and Section 6 offers conclusions and options for future research.

2. Shadows and lights of the Porter hypothesis

2.1. The evolution of the debate over the last 20 years

Up until the development of the PH framework, general thought was that the fulfilment of environmental regulations would be likely to reduce the competitiveness of the compliant sectors and increase firm production costs compared with not compliant industries.

On the contrary, the PH seems to test the potential complementarities and private beneficial effects of properly designed environmental regulations, which are likely to emerge in a dynamic context where induced innovation and environmental strategies co-evolve (Wagner, 2007). Since the early 1990s a set of various hypotheses ranging from micro to macro frameworks have emerged under the umbrella of the PH. During the past two decades, we witnessed a hybridization starting from pure managerial business approaches relying on case study analyses (Esty and Porter, 1998, and as examples, articles by Porter in the special issue on 'Greening the economy' of March 2010 on the *Harvard Business Review*) to environmental economics essays dealing with micro and macro issues (Ambec and Barla, 2002, 2006; Ambec and Lanoie, 2008; Ambec et al., 2010; Kriecher and Ziesemer, 2009).

Nonetheless, the early taxonomy proposed by Jaffe and Palmer (1997) and to a somewhat different but complementary extent by Jaffe et al. (1995) seems to be still valid as a general but flexible conceptual framework, where three different versions of the PH were classified.

The strong version starts from a rejection of the profit maximizing behaviour assuming a dynamic evolutionary setting, and it claims that environmental regulation enhances economic performance at least in the medium run for compliant firms, the sector to which they belong and, eventually, the economy as a whole. Regulation shocks could thus be a possible driver of structural change in addition to market related shocks. Heavily changing conditions allow agents considering new opportunities in product and processes, that can fruitfully complement existing innovations, as well as extending the investment perspective over time. Hence, the final effect on economic system as a whole may turn out to be positive through innovation offsets – both through process efficiency and product value enhancement – that may derive from the policy driven early adoption of both technological and organizational

[1] For an extensive review on the innovation effects of ETR, see Salmons (2009).

innovations which is the cornerstone in Porter and van der Linde (1995) argument.[2]

The weak version predicts that additional innovations induced by regulations present opportunity costs on the one hand, but their gross benefits may be higher. The generation of those net benefits is also coherent with the assumption of initial profit maximizing behaviour. Agents will be induced by new constraints to reorganize technology and organization, to improve the coordination of activities, and to align incentives for the purpose of meeting the constraints at a lower cost, resulting in more efficiency and increasing productivity.[3] This view is also compatible with a neo Schumpeterian approach, as the dynamics of innovation is linked and co-evolve with appropriability conditions and generation of new economic performances (Dosi et al., 2006; Malerba, 2006). Nonetheless, this version of the PH cannot say which kinds of innovation are stimulated by regulation, notwithstanding that ' since addition of constraints to a maximization problem cannot improve the outcome, the weak version implies that the additional innovation must come at an opportunity cost that exceeds its benefits (ignoring the social value of reduced pollution)" (Jaffe and Palmer, 1997, p. 610).

Third, but even more relevant here, the so called narrowly strong PH envisages that a more stringent regulatory framework might positively impact only on the green side of the economy, since through the inducement of early innovation in environmental fields the domestic environmental industry can gain competitiveness, where a properly designed regulatory framework may act simultaneously as a stimulus on the supply side and as a market creation action on the demand side.

Jaffe and Palmer (1997) refer to this hypothesis by stating that Jaffe et al. (1995) discuss cases where the PH implies that some regulated firms will benefit even at the expense of other firms. The formers being firms in green sectors. They assert the possibility that such specific gains could in some cases overweight the costs bearing on other sectors, linking that logic to the stronger interpretation of the PH (competitiveness of the country as a whole enhanced by leading innovations induced by stricter regulations).

Thus, environmental regulations may speed up innovation efforts that consequentially enhance economic performances. One reason is that innovation leaders and their followers play a dynamic game, searching for new net profits, where the long run appropriable rent going to early movers is crucial for the PH to be validated.

A second explanation relates to the capacity of regulatory efforts to change the behaviour of firms that are not at the frontier of efficiency, generating win–win options which can be transmitted first at the sector and even at more aggregate level. Firms can in fact often be distant from efficient frontiers: this does not assure the PH but renders it more likely (Lundgren and Marklund, 2010). It is then possible that properly designed regulations bring about favourable conditions such as boosting demand for green products, pricing scarce resources, making unexploited technologies available (Wagner, 2006) and open up the set of choices constrained by production habits towards a re-engineering of routines that allow low hanging fruits to be harvested.[4] The target is not only referring to market prices, but in a Coasian way, inside the firm failures should be tackled (Gabel and Sinclair-Desgagnè, 1998).

Focusing on innovation dynamics, imitation, adoption and selection are the mechanisms by which innovation generally spreads, operates and affects market conditions. In this sense, the PH seems conceptually also in line with threshold models (Davies, 1979) where larger firms are the early adopter, eventually followed by smaller firms through learning by doing and market expansion. Environmental regulations can matter insofar as a lower relative price for green options shifts the threshold down, influencing both technological production costs and investment behaviour, that are two relevant drivers of the selection process (Metcalfe, 1998). If this happens, supply and demand increase benefits the population of Porter-like behaving firms, where innovation diffusion, spillovers and imitation can play a role in the supply side (supply interacts with imitation), occurring at various level of sector and economic systems (Griliches, 1992; Simon, 1957, 1972, 1991). Environmental policy even if applied at national level (thinking of the stronger stringency of Germany and Nordic countries in the EU) can stimulate the rate of growth of incremental technological change, then together with imitation and through trade mechanisms, diffusion is stimulated in other sectors and systems (Antonelli, 1989).

We argue that the PH assumes that a certain regulation is needed to cope with the appropriable part of innovation: instead of being only useful for dealing with the public component exposed to market failures, regulations can also drive and solve distortions in the profit side (Löschel and Rübbelke, 2009). The sources of competitive advantages in the PH framework that are associated with the reconfiguration of this value chain actually touch all environmental and social realms (Porter, 2010).[5]

Though general figures and trends could be largely in favour of the PH when analysed qualitatively on the aggregate long run figures, at least for major economies (Jaffe et al., 1995 for a view on the US) and simulations have also provided enough support (Popp, 2005a), specific empirical studies on the PH have often not been successful in finding robust support for the strong argument so far. Some general support was recently provided by Lanoie et al. (2008) who show that regulations positively impact productivity, especially in sectors which are exposed to international competition.

Even the weak argument has not found unanimous robust confirm. Nevertheless, more recently, there has been increasing empirical evidence to support the argument that stringent environmental policies lead to valuable technological innovations specifically in the energy sector (Costantini and Crespi, 2008; Johnstone et al., 2010; Lanjouw and Mody, 1996). There is also increasing consensus on the potential win–win effects deriving from well combined environmental and innovation strategies, both on the private and public side (Jaffe et al., 2005). In this respect, the use of an appropriate mix of innovation and environmental policies emerges as a crucial factor in directing economic systems towards sustainable and competitive paths of economic growth (van den Berg et al., 2007).

[2] Such new opportunities, namely green technological advancements, are compatible with both the creative destruction (new firms entering the market) and the creative accumulation paradigms that refer to the Schumpeterian tradition (Malerba and Orsenigo, 1997). In the latter situation, new opportunities may complement existing ones, increasing returns to scale deriving from higher profit exploitability and knowledge cumulativeness.

[3] For a specific discussion on energy efficiency enhancements induced by new management practices see Bloom et al. (2010).

[4] The link between the theoretical background of PH and the environmental economics evolutionary arena is also proposed by van den Bergh et al. (2000), who affirm that habitual behaviour and Simon's satisfying (bounded rationality) behaviour can explain the un-reaped economic benefits associated with potential energy conservation measures in many firms. Porter-like firms are not profit maximisers, but at least cost minimiser adopting strategy to diversify risks in the long run. We may affirm that in Simon's world even second best and third best outcomes, that the agent reaches through its 'satisfactory oriented behaviour', can be dynamically changed in better states of the world if the agent modify its aims and expectations, that is if it innovates. Policy shocks can be ways to modify and affect satisficing behaviour in non optimal flavoured settings.

[5] Along other lines of research that strictly link to the managerial oriented seminal Porter ideas, it is worth noting that corporate social responsibility (CSR) (Lyon and Maxwell, 2008; Portney, 2008; Reinhardt et al., 2008) can be a typical firm's behaviour in economic frameworks characterized by regulated markets, wherein more innovative firms take a long run perspective to increase their mark-up and market shares, coherently with the PH.

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In our opinion, four driving factors may strongly influence direction and robustness of the empirical results. The first one is the economic dimension considered for investigating the impact of environmental regulation on competitiveness. Among others, as a typical example, Gray and Shadbegian (1995) use total factor productivity and plant growth rates, finding that the relationship between abatement costs and productivity is not significant. However, if we go back to the seminal contribution by Porter and van der Linde (1995), the foreign competitiveness flavour was central since strict environmental regulations could enhance competitive advantage, or in other words, it could positively affect export dynamics. In this sense, Becker and Shadbegian (2008) find that environmental regulation has a positive influence on export performance which is far greater than on productivity performance.

The second issue is related to the level of sector aggregation, which is relevant especially when export competitiveness is under investigation. Since the combination and interaction between the environmental regulatory framework and the innovation activities play a crucial role, working at aggregate macro level may reduce the capacity to catch these linkages carefully. Some firm-based or country-based studies are available today such as Lundgren and Marklav (2010) for Sweden or Earnhart and Lizal (2010) for Czech firms, but robust evidence on the existence of the PH is still far from being achieved at a more general level. Though promising and able to capture the high firms heterogeneity, firm-based studies are nevertheless limited by pervasive case study evidence, as is the case in the strict managerial Porter literature, and by the limited dynamic perspective and geographical coverage that econometric firm-based surveys may intrinsically allow. Most of them are providing evidence at country level or at best for a few major countries (Kemp and Pontoglio, 2007).[6]

We thus believe that a sector perspective is for our purposes the most relevant from both applied and conceptual reasons. Regarding the former, it allows a sufficient extension of the data pool exploited for econometric analysis, a good coverage at geographical level, still maintaining a degree of heterogeneity higher than in the macro analyses. It is worth noting that recent works that have analysed relationships between industry performances, environmental regulations and trade stress the importance of a sector-based picture. Among others, Cole et al. (2005, 2010) show how sector idiosyncratic the assessment of the pollution haven effect can be, revealing that the exploitation of industry heterogeneity and inclusion of variables that are hidden by macroeconomic analyses are deemed crucial. We additionally note that recently Cainelli et al. (2009) also show the importance of exploiting both sector and firm data when analysing income–environment–innovation links. Thus, the sector/industry level of the analysis appears to be crucial to provide a more robust possibility to explore more in depth relationships between economic performances and environmental policies, without losing on the other hand generality of results.

Concerning the theoretical layers of our research hypotheses, we observe that innovation and economic dynamics are most fruitfully analysed at sector level. In the seminal works by Malerba and Orsenigo (1997, 2000), the paradigm of technological regimes is the key concept for studying the different ways in which innovative activities are organized and industries evolve over time. More relevant for us, their main finding is that innovative activities are sector specific, insofar as the features of technological environments are common to groups of industries, while they are invariant with respect to the institutional context. They thus find differences across sectors in the patterns of innovation and dynamic economic performances, and similarities across countries. Evidence also shows that knowledge base of innovative activities varies greatly across industries in terms of contents and sources (Malerba, 2007).

This sector-based approach turns to be a key conceptual justification for studying sectors at various degree of aggregation in a realm, such as that of the PH, wherein innovation plays the major role. This is not aimed at excluding the relevance of national systems of innovation which can be captured by country fixed effects in empirical analyses (Breschi et al., 2000). This is to affirm that an analysis based on sector/technological regimes or classes maximizes the possibility of investigating the behaviour of agents in dynamic innovative intense contexts. Though in this sector perspective agent's behaviour is less appropriate, complementary comments on the relevance of evolutionary dynamics concepts such as bounded rationality, uncertainty and diversification among others are relevantly integrated and useful for a more robust foundation of the PH and for a discussion on the properties of environmental policies. In the Porter idea, well designed policies should take into account multiple objectives and types of behaviour, not just maximization and short run efficiency.

The third issue relates to the choice on how to model the environmental regulatory framework. There are contributions relying on Pollution Abatement Control Expenditures (PACE), as in the case of US firms subject to emission trading whose productivity seems to be positively influenced by such a regulatory framework (Shadbegian, 2010). On the contrary, Gray (2010) finds negative effects on productivity driven by pollution abatement costs economically negligible, whereas Becker (2010) exploits a PACE spatially dimensioned country-specific regulatory index for all manufacturing US industries and productivity effects are again overall negligible. Empirical analyses based on more general policy measures such as environmental or energy taxation seem to find more robust results in favour of a PH, but only in its weaker version for a specific green sector (Costantini and Crespi, 2010). This discrepancy may be due to the fact that PACE are a rough proxy of environmental policy stringency with regard to indexes (van Beers and van den Bergh, 2003) or real taxation data, since they are subject to strong time volatility (Kemp, 1997) and their pervasiveness is strongly reduced by administrative control failures.

Finally, it seems that most contributions finding robust evidence supporting the PH carefully account for temporal adjustments, since competitive advantages take time to occur after the entry into force of any regulatory novelty (Lanoie et al., 2008). This means that dynamic models need to be necessarily modelled and carefully estimated if such temporal discrepancy is to be considered. This issue is also highly consistent with the above mentioned Schumpeterian tradition which places at the heart of the research agenda the relationship between innovation and the dynamics and evolution of industries.

2.2. *Core research hypotheses: policy and innovation export drivers*

Building on the previous conceptual background, this paper attempts to test both strong and narrowly strong sides of the PH tale. For the purposes of our export oriented analysis, we start from and stick to the taxonomy proposed by Jaffe and Palmer (1997) described above, since they underline export flows as a main indicator of competitiveness when environmental regulations effects are tested, both in the strong and narrowly strong versions of the PH, where the latter is focusing on the competitive advantages of domestic environmental industry.

Considering main shortcomings of past empirical contributions on testing the existence of the PH, we propose some methodological and empirical advancements in order to empirically estimate both

[6] Even valuable efforts such as the elicitation of eco-innovation adoptions in the last wave of Community Innovation Survey (CIS) at the EU level are constrained by the cross-section nature of data.

strong and narrowly strong versions of the PH focusing on export dynamics of the European Union over the period 1996–2007.

Consequently, our first set of research hypotheses, coherently with a strong PH, regards the effects on competitive advantages (export flows) deriving from public environmental policies [HP1]. Since the strong PH is under investigation, export flows are related to four macro sectors classified by their technological content (OECD, 2008), representing the whole manufacturing sector of each country. This is in line with the industry based reasoning presented by Jaffe et al. (1995) and follows the sector-oriented rationale we have already discussed. Hence, we can test whether environmental public policies – represented here by energy and environmental tax revenues – have positive effects on sector-specific export competitiveness across technological homogenous classes. The innovative response of one sector to environmental taxation and regulation depends on its technological contents and on the importance of energy and environmental costs as a share of turnover. To some extent we may well expect that the higher the technological and energy contents of the production process, the more likely the regulatory costs will turn into economic benefits. Differences of evidence across technological classes will help us to confirm such research hypothesis.

Environmental regulation is here represented by energy and environmental taxation which captures effects that pass through the inducement of those innovations, increasing resource efficiency and reducing the tax base. Given the data availability of energy and environmental taxation in the EU, we primarily test the drivers that are clearer with respect to what they capture, representing the core factors of any ETR. We also prefer taxation to indexes related to environmental policy stringency since they are often subjectively elicited from managers or policy makers' surveys and could be deemed somewhat arbitrary in their construction.

Second, we estimate the narrowly strong PH that claims the possibility that environmental regulatory frameworks could foster export dynamics of industries producing environmental-friendly goods whether they are represented by public policies [HP2] or by private and voluntary actions [HP3]. According to Wagner (2008), the green content of goods entering international markets implicitly refers to a techno-organizational structure that is biased towards ecological innovation. Behind general national comparative advantages linked to national systems of innovation one may find that competitiveness concentrates in industry segments such as environmental technology sectors. Those sectors could belong to both Schumpeter mark I or II technological classes (Malerba and Orsenigo, 1997). Insofar as green technologies may be characterized by discontinuity, new and greener sectors may belong to mark I, or we may expect mark I patterns be turned over by mark II. However, mark I patterns could still prevail, given that cumulativeness and technological complementarities could favour monopolistic power over new entrants. Within the PH debate, we potentially face a narrowly strong argument insofar as the green competitive advantage of a country may be enhanced by long term effects of regulations on eco-innovations (Rexhauser and Rennings, 2010). At the time being, it is still not possible to study a pure eco-innovation oriented PH because further steps should be done to link innovation indicators to output or performance measures, such as export flows, in the environmental industry. Thus, our focus is forced to be on the green content of the exported environmental goods, rather than on the green technologies adopted in the production process.[7]

According to the strong PH version [HP1], in the [HP2] we analyse if and how green exports are influenced by environmental and energy taxation at the country level.

We may also expect private compulsory and voluntary actions – here represented by PACE and Environmental Management System (EMS) – to play a role in enhancing economic competitiveness [HP3]. Environmental organizational innovations may complement tax-based environmental policy and provide further pillars to competitive advantages (Johnstone and Labonne, 2009; Rennings et al., 2006). EMS oblige firms to regularly report resource efficiency on all environmental grounds-and by their strict connections and complementarity to green technological innovations. Thus, organizational innovations extend the scope of innovative measures in line with the Porter original scheme, for which process and product innovations generate the additional value stemming from the reshaping of the value chain (Roediger-Schluga, 2004). In effect, Ziegler and Nogareda (2009) recently studied the co-causation link since the two innovation realms can thus be interrelated and provide correlated or additive effects to innovation and economic performance.[8]

From a general point of view, we are aware that the PH should be tested using properly designed policy actions which mainly correspond to market-based instruments. Stringency is one part of the tale, the form of regulation is the other (Bernauer et al., 2006). Wagner (2006) notes that when testing the PH, this efficiency, which is higher the closer we are to economic instruments such as taxes instead of command and control tools, should be assumed, in a meaning of efficiency that integrates mainstream and behavioural/evolutionary economics related issues. Additionally, economic instruments could change the firms' behaviour by incentives provided through liability based tools (Gabel and Sinclair-Desgagnè, 1998).

We observe that the *efficiency without optimality* associated to market based instruments is a reasonable assumption that also derives from the seminal contribution by Baumol and Oates (1988) and links to environmental policy agendas that take into account both welfare economics and evolutionary economics. Price based policies remain relevant even if they become less dominant (less efficient in a dynamic and uncertain world) with respect to other tools. The effects on innovation and competitiveness are considered as well as cost-efficiency features. The charges and standards approach says that setting a sufficient variety of environmental policies can contribute to the efficiency of a program for controlling externalities, and this is more relevant the higher the social costs, such as in the case of climate change and hazardous pollution. A satisfying procedure that does not search for the global optimum can approach the least cost solution related to a specific target of interest. It thus can be designed as to approximate the Pigouvian outcome. What is really worthwhile for the PH environment is that "it is significant that the validity of this least cost theorem does not require the assumption that the firms generating the externalities are profit maximizers or perfect competitors. All that is necessary is that they minimize cost for whatever output they select" (Baumol and Oates, 1988, p. 165).[9] Efficiency is then invariant with respect

[7] This choice is reinforced by Kemp (2010), affirming that systematically collected data on eco-innovation are far from being available. The most important sources are patent data, sales and exports data of environmental goods and services, and capital investments and operating expenditures on pollution abatement, but export flows of green technologies are still far from being a consolidated knowledge.

[8] Nevertheless, EMS effects on economic performance are not to be taken for granted in any case and strictly depend on the links to other innovation and asset specificities they create (Triebswetter and Wackerbauer, 2008; Wagner, 2008). To this purpose, Sinclair-Desgagnè (1999) recognises the importance of corporate liability and standards for EMS as complements to economic instruments in the good design of Porter-like regulations.

[9] This statement places the emphasis on efficiency and optimality based on objective functions maximisation that is obeying to marginal cost incentives, but does not disregard the role of corrected prices to tackle externalities. Static efficiency loses power and turns into a different meaning, more linked to cost rather than profit related behaviour. Environmental innovation tackles externality reduction in the

to market structures and firms behaviour. This really seems the real world application of policies.[10] This moves the discussion on effectiveness and efficiency properties of environmental policy in an evolutionary framework where dynamic (not just static) innovation and the Simon's idea of imperfect agent's rationality and uncertainty are at the heart of any reasoning (Rammel and van den Bergh, 2003; van den Bergh et al., 2000). This is also consistent with the Porter managerial approach, for instance in the way both Porter and evolutionary thinking address the role of diversity. It is a necessary attribute of firm behaviour that both minimise risk and enhance the chances of survival in the market by increasing competitiveness. A firm that extensively invest in many social and environmental strategies diversify its innovative strategy and take a long run perspective, also implying a bounded rationality that motivates diversification (Earl and Wakeley, 2010).

In order to analyse the contextual role of environmental regulation and innovation efforts, sector-specific innovation related factors are included as additional drivers of competitiveness in the estimations. Although the potential impact of a general regulatory framework may be highly differentiated among manufacturing sectors whose technological content is not homogeneous, our sector disaggregation is clearly helpful when disentangling the pure innovation effect related to the specific sector characteristics from an inducement effect produced by environmental regulation stringency. Since any innovation indicator suffers from intrinsic limits (Kemp and Pearson, 2007; Bernauer et al., 2006), we have tried to exploit different innovative indicators to capture a variety of actions (as described in Section 4), while still retaining the representation of sectoral features as a primary goal.

Finally, we adopt an econometric strategy allowing to specifically consider trade competitiveness in a temporal dynamic structure. To this end, we have chosen a gravity equation framework taken from the international economics literature since it constitutes a theoretically and statistically robust basis for analysing the impact of specific events or structural features on trade effects without losing the geographical pattern dimension (Picci, 2010). Moreover, according to the discussion of the PH stressing different effects in a dynamic perspective both for environmental policy and innovation drivers, we have taken recent estimation advancements specifically developed for dynamic panel gravity models.

To sum up, we list our research hypotheses. The first regards a specification of the strong PH version. It verifies whether energy and environmental taxes positively drive economic competitiveness on the international markets, focusing on the manufacturing sector as a whole, though subdivided into four technological classes. We can thus appreciate how technological content diversity associates to different PH evidence [HP1]. We then verify whether a narrowly strong PH version is valid if we pay attention to the export dynamics of environmental goods driven by public environmental policies [HP2]. Finally, we test a third hypothesis on whether, in a narrowly strong PH context, compulsory (PACE) or voluntary (EMS) private actions are playing a role as a driver for export dynamics of environmental goods [HP3].

3. The gravity model for trade analysis

According to a generalized gravity model, the volume of trade between pairs of countries X_{ij} is a function of their incomes, populations, geographical distance and a set of dummies representing various aspects:

$$X_{ij} = Y_i^{\beta_1} Y_j^{\beta_2} POP_i^{\beta_3} POP_j^{\beta_4} DIST_{ij}^{\beta_5} Z_{ij}^{\beta_6} F_i^{\beta_7} F_j^{\beta_8} \exp(\alpha_{ij} + \gamma D_{ij}) u_{ij} \quad (1)$$

In this specification, Y_i and Y_j indicate the GDPs of the exporter and the partner, respectively, POP_i and POP_j are exporter and partner populations and $DIST_{ij}$ measures the geographical distance between the two countries' capitals (or economic centres). The basic idea is that trade relations are influenced by the economic size of the trading partner where the income and population dimensions are proxies of demand and supply of the importer and the exporter, whereas geographical distance generally represents trade costs. Z_{ij} represents any other factor aiding or preventing trade between each pair of countries, whereas F_i and F_j represent all other specific exporter and partner features which may affect trade flows. The model may also include dummy variables (D_{ij}) for trading partners sharing a common language, a common border, or the existence of past colonial relationships, as well as trading blocs' dummy variables. Finally, α_{ij} represents the specific effect associated with each bilateral trade flow, as a control for all the omitted variables that are specific to each trade flow, whereas u_{ij} is the error term.

Early theoretical contributions attempted to derive the gravity equation from a model that assumed product differentiation (Anderson, 1979), monopolistic competition (Bergstrand, 1985) and product differentiation with increasing returns to scale (Helpman, 1987). More recently, Anderson and van Wincoop (2003) derived an operational gravity model based on the manipulation of the Constant Elasticity of Substitution (CES) system that deals with the issue of Multirateral Resistance Terms (MRTs). According to Baldwin and Taglioni (2006) and Baier and Bergstrand (2007), by including specific country-pairs' time-variant effects, the MRTs can also be represented appropriately for a panel dataset where country effects may be interpreted as the effect of different price structures over trade dynamics. The log-linear form of Eq. (1) in a panel setting accounting for MRTs is thus given by:

$$\begin{aligned} \ln X_{ijt} = {} & \alpha_{ijt} - \sum_{i=1}^{E} \ln P_{it}{}^{1-\sigma} - \sum_{j=1}^{M} \ln P_{jt}{}^{1-\sigma} + \gamma D_{ij} + \beta_1 \ln Y_{it} \\ & + \beta_2 \ln Y_{jt} + \beta_3 \ln POP_{it} + \beta_4 \ln POP_{jt} + +\beta_5 \ln DIST_{ij} \\ & + \beta_6 \ln Z_{ijt} + \beta_7 \ln F_{it} + \beta_8 \ln F_{jt} + \upsilon_{ijt} \end{aligned} \quad (2)$$

where MRTs are represented by the terms $P_{it}{}^{1-\sigma}$ and $P_{jt}{}^{1-\sigma}$ as time-varying multilateral (price) resistance terms for each i-th exporter ($\forall i \in (1, E)$) and j-th partner ($\forall j \in (1, M)$).

Recent advancements in econometric estimation allow two additional issues to be considered related to the potential bias induced by the existence of many zeros in trade flows (Santos Silva and Tenreyro, 2006) and to the autocorrelation of the residual term when the temporal dimension is considered. According to Helpman et al. (2008) (HMR hereafter), a large part of the statistical bias produced by the existence of many zeros is not due to a sample selection problem but to the neglection of the impact of firms' heterogeneity. In particular, a Heckman's two-stage procedure is used to account for selection and heterogeneity biases where some explanatory variables related to the costs of establishing trade flows which affect firms' decisions to export or not are

search for win-win options and multiple dividends. The mere efficiency criterion loses relevance, and "the behaviour of firms aimed at minimising costs (cost effectiveness goal) might preserve the marginal cost concept" (van den Bergh et al., 2000, p. 55).

[10] This is close to the Simon's integration of optimization and satisfaction as two pillars of agent's behaviour. As noted by van den Bergh et al. (2000), there are not optimal policies, but efficient and effective policies, of command and control and/or market based nature, that correct externalities and stimulate innovations, and in any case responses to environmental regulation will not be as evident as in the case of maximising behaviour.

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only included in the first stage equation (Wooldridge, 2002). The two terms obtained from a first-stage probit equation are the extensive margins of trade (representing firms heterogeneity) calculated as the predicted probability of trade from country i to country j and the intensive margins of trade (representing the selection bias) given by the standard inverse Mills ratios.

The second issue concerns a dynamic specification of trade flows that allows serial correlation caused by a strong time persistency in trade flows related to the presence of sunk costs (Bun and Klaassen, 2002). For this purpose, the System GMM (generalized method of moments) proposed by Blundell and Bond (1998) seems to be a proper estimator, making it possible to correct for autocorrelation of residuals while retaining all fixed effects and time invariant variables, unlike an Arellano and Bond GMM estimator. Moreover, Bond and Windmeijer (2002) show that System GMM is more efficient than the Arellano and Bond GMM if the panel has a short time dimension (T) and a large number of cross-section units (N) and if it includes persistent time series.

4. The empirical gravity model and the dataset

The country sample considered here is made up of 14 i exporting countries (all EU15 members where Belgium and Luxembourg are merged) and 145 j importing countries chosen on the basis of data availability and considering that in all cases export flows from i countries to the sum of j countries constitute more than 95% share of total i-th country exports reported by the UNCTAD-COMTRADE database. The time period is 1996–2007 and the full sample therefore covers a total of 24,360 potential observations. Clearly, our panel dataset has a large number of cross-section units (N) and a small time dimension (T) and export flows show strong persistence in the short-run and include many zero values.

The vector of dependent variables is alternatively expressed by export flows from country i to country j at time t for five k sectors representing four distinct macro-sectors distinguished by their technological content and a fifth green sector. In order to estimate the strong PH, we consider four aggregated sectors classified by OECD (2008) as high, medium-high, medium-low and low technology industries by using the ISIC Rev.3 classification (as described in Table A1 in the Appendix A). The narrowly strong PH is tested on the fifth sector defined here as an aggregation of all Harmonized System Classification codes (HS1996) listed in Steenblik (2005) as environmental goods which are currently subject to specific negotiation in the WTO (Table A2). Codes included in the analysis amount to 158 different 6 digit codes and they are classified by different criteria, on the basis of both their innovative content, if they constitute end-of-pipe disposals or more properly, cleaner technologies and the specific environmental theme covered.[11] We have included all codes proposed in the list since we are interested in a general definition of exports with a green content rather than in a specific sector. This choice is also more coherent with the explanatory variables we have adopted on the environmental side, since both environmental regulation and environmental innovation efforts we adopt here are broadly defined. In this case, we assume that environmental regulation and innovation efforts at the country level may foster productivity gains in industries producing environmental-friendly disposals of both types, since compliance with environmental commitments may be achieved by adopting both end-of-pipe disposals and cleaner technologies in the production process.

[11] Figures of trends in revealed comparative advantages (RCA) for EU15 export flows at the aggregate level of the five k sectors are represented in Fig. A1.

The final log-linear equation of our gravity model is:

$$x^k_{ijt} = \alpha_{it} + \delta_{jt} + \tau_{ijt} + \sum_{p=1}^{n} \lambda_p x^k_{ij,t-p} + \beta_1 BORDER_{ij} + \beta_2 dist_{ij} + \beta_3 z_{ijt} + \beta_4 fhet^k_{ijt} + \beta_5 mills^k_{ijt} + \beta_6 inn^k_{i,t-q} + \beta_7 inn_{jt} + \beta_8 envreg_{i,t-q} + \phi \mathbf{D} + \varepsilon_{ijt} \quad (3)$$

where lower case letters denote variables expressed in natural logarithms and upper case letters indicate dummy variables.

The inclusion of time-invariant MRTs suggested by Anderson and van Wincoop (2003) is proxied by country-specific time variant effects (α_{it} and δ_{jt} for exporting and importing countries, respectively) whereas the country-pair specific effect is also included as a time-variant variable (τ_{ijt}) as suggested by De Benedictis et al. (2005) for a panel version of the model. The dynamics and persistence of the dependent variable which produces autocorrelation bias is captured and the lag structure is endogenously determined by serial correlation test ($\sum_{p=1}^{n} \lambda_p x^k_{ij,t-p}$). Finally, potential bias due to zero trade flows is reduced by including the two terms proposed by HMR obtained from the first-stage probit equation as the extensive margins ($fhet_{ijt}$) and the intensive margins ($mills_{ijt}$) of trade, calculated for each k-th sector separately (Martínez-Zarzoso et al., 2010).[12]

The standard variables of a gravity equation included here are the following. $BORDER_{ij}$ is a dummy variable for the existence or non-existence of a common geographical border between each country pair. The log of distance ($dist_{ij}$) is calculated as the great-circle formula (Mayer and Zignago, 2006). We expect the coefficient for $BORDER_{ij}$ to be positive and that for $dist_{ij}$ to be negative since distances are commonly considered as a proxy of transport costs.[13]

Since country effects for exporters and importers approximating MRTs often catch differences in structural dimensions, estimated parameters for unilateral dimensions as GDP or population often lose statistical robustness. Many contributions propose some combinations of variables explaining the role of the economic size of the trading partners in order to build country-pair time variant variables rather than double unilateral ones. Hence, we have chosen to test three combinations, as the most widely used.

In particular, we have considered a measure of relative country size by computing the similarity index of the GDPs of two trading partners (sim_{ijt}) calculated as in Egger (2000):

$$sim_{ijt} = \ln\left[1 - \left|\left(\frac{GDP_{it}}{GDP_{it} + GDP_{jt}}\right)^2 - \left(\frac{GDP_{jt}}{GDP_{it} + GDP_{jt}}\right)^2\right|\right] \quad (4)$$

The larger this measure, the more similar the two countries are in terms of GDPs and the greater the expected share of intra-industry trade.

A synthetic measure of the impact of country-pair size as a proxy of the "mass" in gravity models ($mass_{ijt}$) is given by:

$$mass_{ijt} = \ln(GDP_{it} + GDP_{jt}) \quad (5)$$

since the total volume of trade should be greater the larger the overall economic space represented by the mass.

[12] We have not reported results of probit equations, but they are available from the authors upon request.
[13] A complete list of variables description is reported in Table A4.

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A measure of the distance between relative endowment of domestic assets ($endw_{ijt}$) is approximated by Eq. (6) where GDP per capita is a proxy of the capital–labour ratio of each country:

$$endw_{ijt} = \left| \ln\left(\frac{GDP_{it}}{POP_{it}}\right) - \ln\left(\frac{GDP_{jt}}{POP_{jt}}\right) \right| \tag{6}$$

The larger this difference, the higher the volume of inter-industry trade and the lower the share of intra-industry trade should be.

We have also included sector-specific innovation variables to represent the role of innovative capacity in explaining trade performance for each sector since there is convincing empirical evidence that cumulative domestic innovation efforts are an important determinant of trade competitiveness (Eaton and Kortum, 2002).

The explanatory variable associated with the role of technological innovation for exporting countries ($inn^k_{i,t-q}$) has been built as an adaptation of the stock of knowledge function based on patent count. The stock of knowledge is defined following the accumulation function (Popp, 2002), with the exclusion of the diffusion component.[14] Our data allow patents to be assigned as 4-digit codes of the International Patents Classification (IPC) for inventing industries so that the final stock of knowledge function is:

$$INN^k_{it} = \sum_{s=0}^{t} PAT^k_{is} e^{[-\beta_1(t-s)]} \tag{7}$$

where INN^k_{it} is the knowledge stock in sector k for each i-th exporting country at time t. Here PAT^k_{is} represents the number of patents produced by industry k in country i in year s and s represents an index of years up to and including year t, whereas β_1 is the decay rate. The final variable $inn^k_{i,t-q}$ is calculated as the logarithm of the stock for each year.

With respect to the strong PH, patents granted are counted and aggregated by application year and they are assigned to the industrial sector relying on the classification proposed by Schmoch et al. (2003) and Verspagen et al. (2004) specifically for the EU, referring to 46 industrial sectors, classified by using ISIC Rev.3, which are related to the International Patents Classification codes. We have condensed the 46 sectors into four macro-sectors according to the OECD classification based on technology content (Table A1).

With respect to the narrowly strong PH, since a general consensus on a fully detailed environmental technologies list is far from being achieved, we have computed the specific stock of patents related to the environmental technology sector by taking classes proposed by OECD (2010) and now available at the aggregate level in OECD PATSTAT database. In this case environmental technologies fields (Table A3) represent a small sub-set of potential environmental technology domains, but we have preferred to adopt a consolidated approach relying on an official, although not complete, classification.[15] Nonetheless, since the innovation capacity in a more narrowly defined sector as the environmental goods one may depend on several other factors, especially if we think that it is a highly heterogeneous sector, not reconcilable with a specific industry, we have also tested the role of a more general environmental innovation measure as the public R&D expenditures for environmental purposes taking into account the broadest definition of environmental protection activities. Moreover, we have also controlled for the role of the national innovation systems by investigating the effects played by the whole domestic innovative capacity, broadly represented by total R&D expenditures and a knowledge stock based on patents for the whole manufacturing sector.

Turning to our main sector-based innovation indicator, we argue here that stocks allow an overall knowledge production function to be estimated, considering that in most cases, the capacity to apply for a patent largely depends on previous experience, so that the higher the number of patents granted to a certain firm, the greater the probability that this specific firm will apply for new patents. Moreover, we have used a stock of knowledge function instead of a pure patents count approach because there is convincing empirical evidence that cumulative domestic innovation efforts are an important determinant of productivity and competitiveness of trade flows (Coe and Helpman, 1995; Eaton and Kortum, 1996). By using a knowledge stock we account for an aggregated capacity to produce and accumulate knowledge, thus including the role of prior patenting activities and past R&D efforts. Unlike R&D expenditures and other data on inventive activity, patent data are available in highly disaggregated forms for many countries and sectors as well as for an almost complete time span, notwithstanding their specific role in explaining trade performance as early emphasized by Archibugi and Pianta (1992).[16]

We have taken patent granted by application date due to their better capacity to proxy an innovation output related to R&D efforts (Artz et al., 2010; Thomas et al., 2010), especially in a non-short term context (Dahlin and Behrens, 2005), or when different countries and macro-defined economic sectors (rather than deeply defined sectors or firms) are under investigation (Dutta, 2010). We also assume that the marginal benefits from patenting are at least equal to marginal cost, so that firms apply to European Patent Office (EPO) only for economically valuable inventions. Accordingly, we only consider patents applied to EPO, which are generally more expensive than patenting only in domestic patents offices since EPO provides a uniform application procedure for individual inventors and companies seeking patent protection in up to 40 European countries.

We are conscious that several drawbacks influence the capacity of patents to be a proper innovation measure, since the distribution of patents is skewed as many patents have no industrial application, many inventions are not patented because they are not patentable or inventors may protect the inventions using other methods, and the quality of individual patents varies widely (Griliches, 1990). Accordingly, the results of this paper are best interpreted as the effect of an "average" innovation capacity of each sector rather than a precise indication of the knowledge stock accumulated over time thanks to R&D efforts.

In particular, the fact that not all inventions are patentable and not all inventions are patented is strongly linked to the different propensity to export due to firm heterogeneity. In this sense, the adoption of the HMR two-step procedure, especially with the inclusion of an *ad hoc* variable for firm heterogeneity, allows us to reduce possible biases related to different innovation propensity.

Finally, a proper patent-based innovation measure should account for its real value. A citations-weighted approach is the best way to deal with this issue especially when a sector-specific approach is adopted. Having citations-weighted patents in this dataset is too expensive and out of the scope of this paper. To this

[14] Popp (2002) accounts for the diffusion of technologies by assigning patents to the end-user sectors rather than to the innovation producer alone. Since we are only interested in investigating the knowledge production process and not the diffusion patterns, we have not included the diffusion coefficient.

[15] Fig. A2 in the Appendix represents relative trends for the four macro-sectors of EU15 patent stocks as well as for the specific environmental fields according to the OECD classification, revealing an evident positive dynamics for the high-tech sector, and more recently for the environment-related patents.

[16] The correlation value that we obtained between a total R&D expenditure variable and a total patent-based stock of knowledge variable for our dataset (equal to 0.86 for simultaneous variables and 0.89 if R&D expenditures are taken with one lag), allows us to rely on patents as a good innovation measure.

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end, we have adopted two corrective measures. The first one is the choice for a relatively high decay rate (β_1 in Eq. (7)) equal to 30% compared with a more standard 15% (Hall, 1990). In our model, the decay rate requires a common assumption for all sectors and countries over a 12-year period, where a strong variance occurs in all fields (sectors, countries and time), as many contributions also reveal for European Union countries, reporting decay rates in the range of 10–50% for sectors and countries considered here (Pakes and Schankerman, 1984; Shankerman, 1998, Shankerman and Pakes, 1986). This means that an average decay rate is an *a priori* assumption which could be valid for one sector/country but may not be suitable for another. Since our estimations rely on a panel setting, we have assumed a 30% decay rate as the average value of the range 10–50% empirically found specifically for our countries.[17]

We are conscious that this procedure does not allow specific patent features to be taken into account since its economic value is also given by citations frequency. For this purpose, the second corrective measure is to consider only EPO (European Patent Office) applications. Since EPO applications are relatively more costly than patenting in national offices, the likelihood that firms decide to apply to EPO only for economically viable inventions is higher.[18]

Since the same dimensions must be taken into account for both *i* and *j* countries in a gravity model in order to catch the propensity of the *j*-th country to import goods with different technological characteristics, according to Filippini and Molini (2003), we computed an innovation-related variable relying on the concept of technological capabilities proposed by Archibugi and Coco (2004). The final formulation of our inn_{jt} index for each country *j* at time *t* represents the diffusion of technological infrastructures and the creation of human capital and is as follows:[19]

$$inn_{jt} = \frac{1}{2}\left[\frac{1}{3}\left(\frac{\ln(Tel_{jt})}{\ln(Tel_{\max t})} + \frac{\ln(Internet_{jt})}{\ln(Internet_{\max t})} + \frac{\ln(Elec_{jt})}{\ln(Elec_{\max t})}\right) + \frac{1}{2}\left(\frac{\ln(Edu_{jt})}{\ln(Edu_{\max t})} + \frac{\ln(Fdi_{jt})}{\ln(Fdi_{\max t})}\right)\right] \quad (8)$$

where per capita fixed and mobile telephone lines (Tel_{jt}) and Internet subscribers ($Internet_{jt}$), per capita electricity consumption ($Elec_{jt}$), secondary gross enrolment ratio (Edu_{jt}) and Foreign Direct Investment inflows as percentage of GDP (Fdi_{jt}) are considered.

A final group of core covariates ($envreg_{i,t-q}$) refers to several measures of environmental instruments adopted by each *i*-th exporting country such as energy and environmental taxation and private actions played by firms both compulsory (such as pollution abatement expenditure as percentage of GDP, PACE) and voluntary such as EMS implementation.[20]

Finally, in order to investigate whether some structural breaks occurred, we tested a set of dummies for temporal shocks including the adoption of the euro currency unit and the entry into force of the EU Emissions Trading Scheme (ETS) for the period 2005–2007. Regarding this last point, we must stress that it is rather too early to unambiguously assess an ETS effect in the first phase we capture, although some studies focusing on innovation and price effects are present (Alberola et al., 2009 among others). The mechanism through which this policy instrument drives competitiveness is similar to other tools, but ETS is at risk of price volatility and may produce uncertainty for investments. What matters is the degree of induced innovation that may take time and be highly sector specific relying on incremental or radical innovation, hence we can expect heterogeneity across sector classes.

Geographical dummies were also tested (vector **D** in Eq. (3)) in order to catch potential clustering effects.[21]

5. Empirical evidence

5.1. The drivers of export performance for the strong PH

5.1.1. Structural results in a gravity context

According to the definition of our first research hypothesis [HP1], we are interested in understanding if the environmental regulatory framework, mainly in its market-based definition, plays some role in enhancing export competitiveness of EU manufacturing sectors (Table 1).

Although the potential impact of a general regulatory framework may be highly differentiated among manufacturing sectors whose technological content is not homogeneous, while considering that a Porter-like effect mainly depends on induced innovation, our four macro-sector disaggregation is clearly helpful when disentangling the pure innovation effect related to the specific sector characteristics from an inducement effect produced by environmental regulation stringency.

As a first general result, the use of a dynamic panel estimator appears to be strongly required since the coefficients for lagged values of exports are always statistically significant. The optimal lag structure (two lags) has been selected on the basis of the autocorrelation tests over the residual terms, when the *p*-value of the AR(2) test does not fail to reject the null hypothesis of absence of serial correlation.[22] The Sargan test on over-identification of instruments to control for endogeneity – in our case, the *i*-th country innovation and regulation variables as found previously in Jug and Mirza (2005)-reinforces such a structure.

[17] Since the choice for a higher decay rate may result in some biases for the estimation results, we have made a sensitivity analysis for the strong PH applying a 15% decay rate. Results remain consistent and statistically robust. For the sake of simplicity we do not report results for this sensitivity analysis but they are fully available upon request by the authors. We thank an anonymous reviewer for addressing this point.

[18] In this paper we are forced to adopt a sector specific approach in the sense that we cannot address the influence by the innovation capacity of the other sectors and regions in a well-known knowledge spillovers framework. When working in a gravity context, we have to counterbalance variables for exporters and importers. In this case while knowledge spillovers for exporting countries can be easily computed, the same dimension is hardly available for importing countries. Nonetheless, we are conscious that this is a crucial factor to be addressed and our next research step will be to investigate this topic by adopting a different theoretical model allowing inter-sectoral effects.

[19] Since the innovation dimension of the importing country mainly relates to a better qualification of demand for imported goods, it is usually taken as an exogenous variable, completely independent from export flows coming from foreign countries, and it has usually a contemporaneous effect. We have tested several lag structures, where the valid specification results in a no lag structure.

[20] The inclusion in a gravity model of a unilateral dimension as in the case of environmental regulation of *i* countries with no correspondence for the partner countries may produce biased results as an omitted variable problem may arise. We have tested several measures in our model which could proxy the regulatory efforts of importing countries, as CO_2 emissions or energy intensity reduction trends but results do not change substantially while we will lose a large number of observations. We have also thought about using an institutional quality measure as a common variable used in the environment-development literature (Farzin and Bond, 2005) but in this case, even more serious problems may arise since we have included an institutional quality distance between *i* and *j* countries as our key variable for the panel first stage probit estimation to compute the extensive and intensive margins of trade. Results reported in our empirical estimations thus omit such variable from the *j* countries side.

[21] The exact variable definition and statistical source are described in Table A4 in the Appendix. Descriptive statistics, and correlation matrix for main variables are reported in Tables A5–A6 in the Appendix.

[22] The only exception in the medium-high sector where AR(2) fails to exclude autocorrelation. In this specific case, we have considered the AR(3) test which allows excluding serial correlation as suggested by Bun and Klaassen (2002) when two lags for the dependent variable is included.

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Table 1
The influence of public environmental policies on export dynamics of technology-distinguished sectors [HP1].

	High tech		Medium-high tech		Medium-low tech		Low tech	
Export$_{ij(t-1)}$	0.473^{***} (14.86)	0.466^{***} (14.54)	0.458^{***} (13.98)	0.435^{***} (14.75)	0.389^{***} (11.57)	0.392^{***} (11.73)	0.474^{***} (11.76)	0.485^{***} (13.08)
Export$_{ij(t-2)}$	0.224^{***} (6.98)	0.216^{***} (6.79)	0.255^{***} (7.87)	0.268^{***} (8.30)	0.168^{***} (5.15)	0.173^{***} (5.43)	0.265^{***} (7.18)	0.292^{***} (8.13)
Distance$_{ij}$	−0.105 (−1.05)	−0.144 (−1.48)	-0.213^{***} (−3.12)	-0.224^{***} (−3.14)	-0.391^{***} (−3.62)	-0.439^{***} (−4.07)	-0.364^{***} (−3.12)	-0.352^{***} (−3.58)
Mass$_{ijt}$	0.245^{**} (2.31)	0.343^{***} (3.22)	0.422^{***} (4.08)	0.343^{***} (3.63)	0.665^{***} (4.63)	0.591^{***} (4.93)	0.198^{**} (2.24)	0.140 (1.67)
Similarity$_{ijt}$	0.296^{***} (2.82)	0.370^{***} (3.65)	0.269^{***} (3.48)	0.260^{***} (3.26)	0.387^{***} (3.93)	0.379^{***} (3.92)	0.148^{**} (2.04)	0.115 (1.87)
Firms heterogeneity$_{ijt}$	−0.407 (−0.86)	0.168 (0.39)	0.038 (0.07)	0.409 (0.85)	-1.566^{***} (−3.51)	-1.497^{***} (−3.43)	−0.659 (−1.20)	−0.758 (−1.43)
Mills$_{ijt}$	−0.011 (−0.71)	−0.02 (−1.52)	−0.013 (−1.43)	-0.018^{**} (−2.21)	0.014 (0.79)	0.01 (0.56)	−0.002 (−0.28)	0.001 (0.18)
Knowledge$_{iPAT(t-1)}$	0.164^{***} (2.60)	0.275^{***} (4.40)	0.133^{***} (2.96)	0.169^{***} (3.78)	0.101^{**} (2.40)	0.082^{**} (2.08)	0.060 (1.88)	0.052^{**} (1.98)
Knowledge$_{jt}$	0.086^{**} (2.30)	0.066^{*} (1.81)	0.101^{**} (2.47)	0.028 (0.92)	0.162^{***} (3.06)	0.141^{***} (2.67)	0.011 (0.29)	−0.001 (−0.02)
Energy tax$_{i(t-1)}$	0.354^{**} (1.98)		0.178 (1.33)		0.381^{***} (2.71)		0.009 (0.07)	
Environment tax$_{i(t-1)}$		0.242^{***} (2.78)		−0.047 (−0.78)		−0.130 (−1.74)		0.002 (0.05)
Euro	0.558^{***} (12.32)	0.480^{***} (10.26)	0.671^{***} (21.28)	0.721^{***} (25.88)	0.727^{***} (21.25)	0.201^{***} (8.74)	0.176^{***} (9.00)	0.679^{***} (20.01)
Ets	-0.194^{***} (−7.00)	-0.215^{***} (−8.16)	-0.238^{***} (−10.49)	-0.248^{***} (−11.38)	-0.184^{***} (−6.63)	0.380^{***} (8.29)	0.245^{***} (5.92)	-0.265^{***} (−12.58)
Country-pair effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country-specific effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No observations	15,236	15,236	15,377	15,377	15,209	15,209	14,519	14,519
Wald test	15,052	17,457	30,771	38,627	14,563	15,017	19,255	21,651
AR(1)	−3.26 (0.01)	−3.12 (0.02)	−2.14 (0.03)	−2.50 (0.01)	−1.80 (0.07)	−1.87 (0.06)	−6.18 (0.00)	−1.34 (0.18)
AR(2)	1.36 (0.18)	1.32 (0.19)	2.13 (0.03)	2.24 (0.03)	0.70 (0.49)	0.73 (0.47)	0.71 (0.48)	0.21 (0.83)
Sargan test	30.31 (0.51)	30.44 (0.51)	44.17 (0.06)	36.13 (0.24)	27.94 (0.62)	29.21 (0.56)	41.07 (0.11)	28.37 (0.61)
Mean VIF	2.42	2.38	2.57	2.52	2.20	2.15	2.37	2.32
Condition number	27.28	27.16	27.09	26.86	12.03	12.96	11.66	11.20

Notes: Two-step robust specification has been used. Robust *t*-statistics in absolute value are reported in parenthesis. (**), (***) Significant *p*-value at the 5%, 1%, respectively. AR(1) and AR(2) are tests-with distribution *N*(0, 1)-on the serial correlation of residuals. Sargan Chi-square test for over identification of restrictions. Mean VIF and condition number test for multicollinearity robustness.

Since multicollinearity could be a problem, we have checked for variance inflation factor (VIF) values for all covariates as well condition numbers for the whole regressions. Some explanatory variables included in Eq. (3) resulted to be highly correlated inducing bias in the estimation results (namely, the contiguity effect, *BORDER*, and the measure of relative endowment, *endow*). By excluding them we have obtained more robust results as all covariates and the mean VIF values for each estimation fall in the more restrictive tolerance value (VIFs < 5.00) showing that multicollinearity is not a concern (O'Brien, 2007). Condition indices also confirm statistical robustness since they are lower than the threshold level (30.00) suggested by Belsley et al. (1980).[23]

Within the vector of control variables valid for all *k* sectors that characterize a gravity model, many factors are significant and consistent with expectations. *Mass* and *Similarity* variables are the key drivers, positively explaining trade dynamics and showing consistent effects across sector classes. Recalling that *Mass* represents the role of global bilateral demand, the higher the value, the greater the influence of demand factors in export dynamics. The positive coefficients for *Similarity* should be interpreted as a sign of the existence of intra-industry trade which is more likely to occur in the medium sectors in the technology ladder, where the importing countries are more likely to have similar factor endowment. As far as *Distance* is concerned, it is significant with a negative expected sign in all cases except for the high-tech sector; we believe this evidence is coherent with the fact that transport costs are less relevant for exporters' decisions over higher value and technological intense goods.

In this case the two-stage procedure seems not to be robust both for firms heterogeneity (*Firms Het*) and selection bias (*Mills*) covariates, except for the medium-low sector where also the *Mass* and *Similarity* covariates present higher coefficients.

Finally, the entry into force of the euro currency unit seems to have increased competitiveness: in a phase (2003–2007) characterized by strong world trade trends, EU sectors were not penalized by a strong currency. This is consistent with the fact that a strong euro is a penalty from a mere price perspective, but stimulates and forces firms in export oriented countries to increase competitive advantages through innovation investments and enhancement in product value, as recent developments in German and Italian trade trends reveal.

[23] We have applied this procedure to each regression and results reported in Tables 1–3 derive from estimations excluding these two covariates. We really thank an anonymous reviewer for addressing this point.

5.1.2. Environmental policies and innovation as drivers for export competitiveness

The high technology sector is the only one presenting significant and persistent impacts on export dynamics related to both energy and environmental tax levers. More specifically, energy and environmental taxation show positive and significant coefficients, meaning that they enhance economic competitiveness without negative side-effects.[24] Quite interestingly, if we consider that estimated coefficients are interpreted as elasticities, we may see that a one point percentage change in energy tax has a greater impact on export dynamics than market conditions (*Mass* and *Similarity*) and innovation capacity ($Know_{PAT}$).

The second macro-sector with medium-high technology content shows a quite different picture, since both energy and environmental taxation are definitely not significant. This finding is the first evidence that the PH should be scrutinized case by case and that sector/policy instruments heterogeneity matters, coherently with what the literature has found at micro level.

As a proof of the interest of investigating sector-specific features, evidence changes again when analysing medium-low technology sector. In this case energy taxes are significant with the highest coefficient with respect to the other sectors: this is the most robust evidence of the strong PH we find here. This is a relevant result if we consider that medium-low technology sectors are those characterized by quite high energy intensity, corresponding to most sectors included in the Emission Trading Scheme (ETS) in the European Union. In this case, energy taxes typically act as levers of higher competitiveness through the activation of potential efficiency improvements at production level.[25]

With regard to the low-tech sector, both environmental and energy taxation do not play a role. Hence, low-tech sectors seem to be driven in their export performance mostly by structural variables unrelated to innovation and environmental policy but more likely dependent on demand-side factors.

The role of ETS should be interpreted carefully. For those sectors currently excluded from the scheme, ETS seems to discourage export competitiveness, whereas for the medium-low sector, which include all sectors covered by ETS, a negative effect is shown when energy taxation is investigated, while a positive sign emerges combined with the role of environmental regulation. We may interpret this result as an ETS effect strictly related to the medium-low sector, revealing that energy taxation seems to prevail in the inducement effect, quite consistently with the fact that ETS has been compulsory only recently for EU firms. On the contrary, for the first two sectors it is more likely to be interpreted in a more generic global market effect, since these two macro-sectors are recently more exposed to emerging economies competition, as losses or stagnation in revealed comparative advantages (RCA) indices for the total export flows show (Fig. A1 in the Appendix A). This result is far from being conclusive, as further sector disaggregation and longer time series are required to infer on the real impact of ETS on EU firms' competitiveness.

As a first general conclusion we may say that environmental taxes do not emerge as a significant driver of the export dynamics, while energy taxation plays a crucial role in explaining export competitiveness for two specific sectors: the high-tech one where the innovative capacity is higher, and the medium-low one, where compliance costs are relatively higher.

This finding is hardly surprising if we consider that environmental taxes have a lower weight compared with energy taxes and they faced a decreasing share on total revenue in the recent history of most EU countries. More importantly, apart from its relative importance in absolute terms, the great advantage of energy taxation over the other environmental regulation tools relies on its pervasiveness. Since energy is still a necessary and non-substitutable input in the production function, provided that its price elasticity is low, the negative impact on average production costs in the very short run is higher. At the same time, its economic relevancy explains the strong innovative reaction by firms whose medium-term advantages in inventing (mainly belonging to the high-tech sector) and adopting (belonging to the medium-low sector) energy-efficient technologies are larger than short-term costs.

In a strong PH context, where manufacturing sectors represent a broad class of heterogeneous firms and industries, innovation activities could play a key role in explaining changes in trade performance, especially in sectors with the highest technology content. To this end, it is worth noting how the innovative capacity for high and medium-high technology sectors positively affects export dynamics since both size and significance of the coefficients are relevant. As long as some innovation efforts are induced by policy actions, this may constitute an indirect second level benefit arising out of regulatory efforts in environmental and related fields.[26]

Moving down the technological ladder, the effect of innovation coherently shrinks in significance. As far as medium-low technology sectors are concerned, innovation covariates show weaker economic significance. Finally, export flows in the low technology sector seem to be neutral compared with the innovative efforts.

The accumulation of knowledge captured by patents is confirmed as a relevant driver of competitiveness with effects that are significant and coherently fade away with sector technological content. The increasing trends in technological revealed comparative advantages (TRCA) for patent stocks for the high technology sector shown by EU in the analysed period (Fig. A2 in Appendix A) confirm innovation as a structural driver of economic competitiveness.

5.2. The drivers of export performance for the narrowly strong PH

5.2.1. Structural results in a gravity context

As the narrowly strong PH is under investigation, we propose two research hypotheses concerning the effect on the export competitiveness of environmental goods produced by a market-based

[24] The exact definition of the lag structure for environmental and innovation explanatory variables is based on both theoretical assumptions and empirical findings. In order to exclude potential endogeneity with the dependent variable, we have considered these covariates as endogenous regressors taking as instruments their lagged values in a standard System GMM procedure, by taking as a robustness measures the Sargan test for overidentified instruments. Coherently with other empirical analysis (Popp, 2002) the most effective structure seems to be with only one temporal lag. Other lag structures are not significant and specific results are available upon request.

[25] This specific result may be explained if we think about how this environmental regulation variable is built. Since it is an energy tax revenue to total revenue ratio, its growing trend may be the effect of two countervailing forces, an increase in energy taxation and/or a decrease in total revenues. Growth trends of total revenues and energy tax revenues during the period 1996–2007 are quite comparable for all EU15 countries and show that total revenues (excluding energy taxation) increased more than energy taxation for all countries except Germany. We may affirm that energy tax to total revenue ratio is a good proxy of the weight on production costs, since there is not a prevailing reduced labour or other taxes effect. Moreover, including only a pure energy price variable, it does not account for the total cost associate to energy consumption, while energy taxes express the real cost of using energy. Since figures for Germany, United Kingdom and Italy are higher than the rest of EU15, it is also necessary to consider a standardization criterion as the ratio to total revenue in order to catch the relative importance of this component in respect with the general structure of taxation. We thank one anonymous referee for addressing this point.

[26] Since the choice of the patent stock decay rate may change somehow our results, we have made some robustness checks by estimating the same models in the strong PH with a 15% average decay rate. Coefficients remain consistent with the 30% decay rate and statistically robust, also for the environmental regulation variables, revealing that the result is not affected by how the technological stock is depreciated over time.

regulatory framework usually represented by energy and environmental taxation [HP2] and by private compulsory and voluntary actions [HP3] represented by pollution abatement expenditures and EMS adoption.

The empirical evidence found here for the narrowly strong PH is quite similar to the strong PH as far as the structural drivers of export competitiveness are considered. The only exception is given by the coefficient value for the second lag which is lower compared with the strong PH where persistency over time seems to be higher. This difference is a sign of the different role played by sunk costs in trade decisions, considering that there are many products whose export flows have only recently increased among environmental goods.

Trade costs represented by the geographical distance seem to play a crucial role among the structural variables as well as the *Mass* that is also strongly significant, overcoming the impact played by *Similarity*. To some extent, this may be explained by the relative importance assumed by demand-side factors, whereas intra-industry trade is hardly to be detectable in a highly heterogeneous aggregate as the environmental goods one. In this sense, technical knowledge of the importing countries now turns out to be statistically robust with a negative sign, revealing that in this case technological capabilities serve as barriers to trade. To some extent, provided that high endowment of technological capabilities is positively correlated with a higher demand for environmental goods, we can interpret this result as the higher capacity to satisfy demand for environmental goods by domestic production rather than by imports, reinforcing the perception that structural factors from the demand side seem to play a major role in green exports.[27]

5.2.2. Environmental policies and innovation as drivers for export competitiveness

Considering the research question expressed by [HP2] (Table 2), as far as energy taxes are concerned, coefficients are significant from both an economic and statistical point of view when patent-based stock of knowledge or environmental R&D public expenditures are included (Columns 1 and 4).

The relevant evidence is that energy taxes seem to weight more than patents in determining green competitive advantages if we stick to both statistical and economic significance, supporting a fairly robust narrowly strong PH. Green policies help increasing business efforts towards the side of green technological contents. With regard to the general conditions required for environmental regulation setting stressed by the PH, when policies are price-based (as energy taxes are), internationally homogeneous (and this is also the case) and widely diffused, their pervasiveness also ensures their efficacy, starting an inducement effect on the technological pattern and on overall economic competitiveness.

In the other two cases (Columns 2 and 3), energy taxes are statistically overwhelmed when total R&D or specific patents stock for environmental technologies are included. In this case, the nature of the dependent variable is the key factor explaining such results. Energy taxation partially catches the effect of an environmental regulation setting over the export capacity of environmental goods which are characterized by a strong innovative content. Energy saving and management disposals are only a small portion of the environmental goods list as expressed by Table A3 in the Appendix A, whereas the R&D expenditure variable is general enough to express its effects on the dependent variable and, as shown by old and recent works, is an engine of green technological content (Jaffe and Palmer, 1997; Johnstone et al., 2010).[28] When we include the environmental patents stock, energy taxation may well represent an innovation inducement engine, but the correlation with export dynamics is more closely related to the specific innovative capacity in that field.

Energy taxes turn out to be significant when environmental public R&D is included. This is of some interest since it may highlight the extent to which public actions – energy taxation and R&D efforts for environmental protection – are complementary and not undermined by trade-offs in their effects: green taxation and green R&D can efficiently induce environmental technology development without conflicting or overlapping.

When analysing environmental tax effects, their economic significance is rather more robust with regard to energy taxes, differently from the previous strong PH findings. Thus, environmental taxes, generally weaker in their effects when the whole economic system or broadly defined macro-sectors are considered, become now a crucial factor explaining international competiveness in the specific green sector. This result is hardly surprising if we think about the quite high specificity of environmental taxation effects with respect to the higher pervasiveness of the energy regulatory framework.

In this case environmental regulation and innovative efforts do not trade off, while a stronger role emerges when the innovation capacity is measured by the most accurate variable (the environmental patents stock). This outcome could be plausible: the higher the complementarity among factors (such as environmental taxes and private efforts in environmental innovation), the higher the likelihood of virtuous dynamic effects, contributing to the enhancement of green competitive advantages.

In the narrowly strong PH realm, a dummy representing ETS is now positive and significant, but the positive sign of the coefficient cannot probably be stretched to support evidence of a strict correlation between ETS introduction and competitiveness. The positive economic cycle of 2005–2007 at world level and the increasing emphasis on green technologies and green investments may also be captured by this dummy.

In the end, with some different weights, that also depend on the complementarity or substitution features that characterize such levers (Mohnen and Roller, 2005) with regard to other private or public drivers of competitive advantage, energy and environmental taxes effectively contribute to the explanation of green export performance.

Let us now consider our last research question on the narrowly strong PH (Table 3), given by the role played by private actions for environmental purposes [HP3]. The first voluntary action we consider is the number of firms adopting each year at the country level an environmental management scheme (EMS), which we may interpret not only as an environmental action but also as a potential organizational innovation. To some extent, an EMS may increase the value of the exported product and can be an element of asset specific competitive advantages jointly with other innovation adoptions. What we can expect is that the more diffuse is an eco-management behaviour at the firm level, the higher the propensity to invest in green products as the corporate behaviour may also influence management strategic choices towards the green market.

In this case, we have not found any significant effect for all tested specifications, excepting for the fourth one (Column 4) when public environmental R&D expenditures are included. There may be two main reasons. If, on the one hand, EMSs have shown a quite strong increase in their diffusion recently, on the other hand, the diffusion problem may be an over heterogeneous development and

27 Nonetheless, some caution is necessary when interpreting this result since the definition of the technological capabilities index for importing countries is so general that it should be interpreted as a control variable rather than a normative attribute.

28 We thank one anonymous referee for addressing this comment.

Table 2
The influence of public environmental policies on export dynamics of environmental goods [HP2].

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$Export_{ij(t-1)}$	0.726***	0.141***	0.558***	0.757***	0.148***	0.131***	0.134***	0.152***
	(12.33)	(6.67)	(7.13)	(13.69)	(7.34)	(6.16)	(5.72)	(7.22)
$Export_{ij(t-2)}$	0.014	0.059***	0.023	0.012	0.052***	0.045***	0.055***	0.052***
	(0.79)	(3.74)	(1.36)	(0.57)	(3.64)	(2.95)	(3.30)	(3.42)
$Distance_{ij}$	−0.607***	−0.273*	−0.930***	−0.345**	−0.304*	−0.443***	−0.510***	−0.408**
	−(−3.42)	−(−1.66)	−(−4.05)	−(−2.32)	−(−1.77)	−(−2.81)	−(−2.67)	−(−2.32)
$Mass_{ijt}$	0.254***	0.643***	0.398***	0.175***	0.613***	0.519***	0.621***	0.453***
	(3.92)	(4.34)	(4.56)	(3.62)	(4.38)	(3.76)	(4.68)	(3.61)
$Similarity_{ijt}$	0.091	0.334***	0.404***	0.392***	0.251***	0.259***	0.117	0.116
	(1.37)	(3.72)	(3.16)	(4.44)	(3.24)	(3.15)	(1.61)	(1.48)
Firms $heterogeneity_{ijt}$	−0.161	−0.104	−0.367**	−0.469***	0.070	−0.499**	−0.369	−0.809***
	−(−1.10)	−(−0.44)	−(−2.02)	−(−3.62)	(0.27)	−(−2.20)	−(−1.62)	−(−3.94)
Mills $ratio_{ijt}$	0.011**	0.016**	0.005	0.007*	0.019***	0.020***	0.018***	0.022***
	(2.23)	(2.06)	(0.97)	(1.92)	(2.96)	(3.04)	(3.06)	(3.64)
$Knowledge_{jt}$	−0.448***	−0.122	−0.510***	−0.437***	0.059	−0.104	0.023	0.031
	−(−5.24)	−(−1.56)	−(−5.28)	−(−4.70)	(1.11)	−(−1.32)	(0.40)	(0.56)
Energy $tax_{i(t-1)}$	0.506***	−0.128	0.267	0.352**				
	(2.71)	−(−0.42)	(1.34)	(2.31)				
Environment $tax_{i(t-1)}$					0.291**	0.407**	0.225**	0.225**
					(2.18)	(2.50)	(2.22)	(1.96)
$Knowledge_{iPATtot(t-1)}$	0.103***				0.275***			
	(3.37)				(4.60)			
$Knowledge_{iPATenv(t-1)}$		0.280***				0.240***		
		(3.75)				(3.79)		
$Knowledge_{iR\&Dtot(t-1)}$			0.274***				0.521***	
			(2.89)				(4.02)	
$Knowledge_{iR\&Denv(t-1)}$				0.147***				0.174***
				(3.18)				(2.59)
Euro	−0.013	0.022	0.170***	0.15***	−0.005	0.010	0.059	0.046
	−(−0.28)	(0.53)	(5.39)	(4.89)	−(−0.13)	(0.24)	(1.27)	(1.12)
Ets	0.158***	0.117**	0.076	0.095	−0.006	0.152***	0.098**	0.131**
	(5.15)	(2.01)	(1.37)	(1.63)	−(−0.10)	(2.67)	(2.10)	(2.50)
Country-pair effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country-specific effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No observation	15,453	14,567	15,453	15,453	15,453	14,567	15,453	15,453
Wald F-test	283.42	200.09	214.06	280.51	284.73	236.56	229.39	290.01
AR(1)	−14.18 (0.00)	−4.62 (0.00)	−13.98 (0.00)	−14.13 (0.00)	−14.38 (0.00)	−12.38 (0.00)	−14.14 (0.00)	−14.04 (0.00)
AR(2)	−2.14 (0.03)	−0.84 (0.40)	−2.41 (0.02)	−2.07 (0.04)	−1.67 (0.09)	−1.74 (0.08)	−1.61 (0.11)	−1.64 (0.10)
Sargan test	32.75 (0.38)	33.76 (0.34)	29.98 (0.52)	29.35 (0.55)	43.52 (0.07)	32.92 (0.37)	32.65 (0.39)	34.98 (0.29)
Mean VIF	2.15	2.24	2.02	2.27	2.02	2.10	1.94	2.13
Conditional number	23.44	24.11	29.94	27.22	16.5	6.58	25.55	11.11

Notes: Two step robust specification has been used. Robust *t*-statistics in absolute value are reported in parenthesis. (**), (***) significant *p*-value at the 5%, 1%, respectively. AR(1) and AR(2) are tests-with distribution $N(0, 1)$-on the serial correlation of residuals. Sargan Chi-square test for over identification of restrictions. Mean VIF and Condition number test for multicollinearity robustness.

maturity across countries and sectors. Secondly, EMSs can still be implemented as a response to obligation or formal CSR behaviour and not as a substantial action that integrates organizational and technological assets for achieving higher innovative and economic performance. As a clear example, Germany is the absolute leader in environmental goods production (Horbach, 2008) and EMS adoption and it massively exports green products. Nevertheless, even in Germany, firms adopting an EMS are only around 10% of all manufacturing firms; diffusion and effective integration with technological contents are even lower in other countries and nearly zero in most sectors. EMSs have witnessed diffusion but not enough in terms of country and sector coverage and their strategic integration in processes must also be strengthened.

Turning to pollution abatement expenditures (PACE) the picture changes substantially, since they significantly enhance trade competitiveness of the green sector. Moreover, an analysis of combined effects of environmental and innovative strategies proves to be particularly interesting. With regard to total patenting activities, the size of the coefficients is similar to that observed for the HP2 where public environmental policies are under investigation, but the economic impact of the specific environmental patents stock results here higher than in the previous estimations set, highlighting a joint significant effect of innovative and abatement expenditures at the private level when specific eco-technological domains are considered.[29] The reason may be that a high level of PACE fosters

[29] For a comparison with Hamamoto (2006), we have also tested the role played by private actions (PACE and EMS) in the strong Porter hypothesis estimations, but results are not robust. This is explained by considering how narrow such private intervention is compared with the broad range of goods classified in the four technology- macro-sectors.

Table 3
The influence of private environmental actions on export dynamics of environmental goods [HP3].

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$Export_{ij(t-1)}$	0.143***	0.152***	0.141	0.163***	0.148***	0.142***	0.131***	0.146***
	(7.44)	(7.46)	(1.00)	(7.79)	(7.24)	(6.78)	(5.61)	(6.94)
$Export_{ij(t-2)}$	0.054***	0.07***	0.076	0.081***	0.057***	0.052***	0.059***	0.057***
	(3.80)	(4.48)	(0.78)	(4.90)	(3.74)	(3.38)	(3.48)	(3.54)
$Distance_{ij}$	−0.374**	−0.357**	−0.386	−0.355**	−0.451***	−0.356**	−0.355**	−0.495***
	−(−2.27)	−(−2.13)	−(−1.30)	−(−2.23)	−(−2.84)	−(−2.19)	−(−1.96)	−(−3.20)
$Mass_{ijt}$	0.618***	0.559***	0.735**	0.386***	0.776***	0.572***	0.950***	0.517***
	(4.29)	(4.27)	(2.01)	(3.63)	(5.12)	(3.97)	(5.78)	(4.43)
$Similarity_{ijt}$	0.309***	0.375***	0.224**	0.202**	0.376***	0.392***	0.207**	0.190**
	(3.65)	(4.47)	(2.51)	(2.54)	(4.48)	(4.61)	(2.37)	(2.37)
Firms $heterogeneity_{ijt}$	0.136	−0.152	−0.232	−0.706***	0.551	0.160	0.218	−0.361
	(0.55)	−(−0.71)	−(−0.11)	−(−3.67)	(1.93)	(0.65)	(0.92)	−(−1.72)
Mills $ratio_{ijt}$	0.011	0.021***	0.017	0.016**	0.004	0.008	0.011	0.015**
	(1.79)	(2.68)	(0.33)	(2.45)	(0.66)	(1.17)	(1.59)	(2.50)
$Knowledge_{jt}$	−0.146**	-0.139	−0.132	−0.100	−0.070	−0.078	−0.116	−0.083
	−(−2.08)	−(−1.79)	−(−0.70)	−(−1.26)	−(−0.91)	−(−1.00)	−(−1.37)	−(−1.07)
$Emas_{i(t-1)}$	0.037	0.047	0.062	0.135***				
	(1.30)	(1.34)	(0.47)	(4.17)				
$Pace_{i(t-1)}$					0.274**	0.294***	0.285***	0.373***
					(2.32)	(2.62)	(2.62)	(3.67)
$Knowledge_{iPATtot(t-1)}$	0.284***				0.287***			
	(4.89)				(4.56)			
$Knowledge_{iPATenv(t-1)}$		0.318***				0.327***		
		(5.15)				(5.17)		
$Knowledge_{iR\&Dtot(t-1)}$			0.616**				0.730***	
			(2.34)				(4.69)	
$Knowledge_{iR\&Denv(t-1)}$				0.071				0.130
				(0.87)				(1.70)
Euro	0.011	0.034	0.082	0.043	0.042	0.081	0.030	0.156***
	(0.27)	(0.68)	(0.81)	(1.01)	(1.04)	(1.52)	(0.57)	(2.94)
Ets	0.077	0.096***	0.038	0.154***	0.033	0.085**	0.129***	0.120***
	(1.24)	(2.32)	(0.69)	(2.73)	(0.48)	(2.01)	(2.62)	(2.70)
Country-pair effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country-specific effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No observation	15,333	14,447	15,333	15,333	15,453	14,567	15,453	15,453
Wald *F*-test	292.02	225.31	271.23	315.04	291.46	226.01	244–32	280.17
AR(1)	−13.91 (0.01)	−5.2 (0.03)	−13.85 (0.01)	−13.97 (0.00)	−14.35 (0.00)	−12.53 (0.00)	−14.11 (0.01)	−14.27 (0.00)
AR(2)	−1.67 (0.11)	−1.23 (0.22)	−2.59 (0.03)	−2.27 (0.02)	−1.85 (0.06)	−1.93 (0.06)	−1.91 (0.06)	−1.73 (0.08)
Sargan test	33.36 (0.35)	29.30 (0.55)	33.02 (0.37)	33.00 (0.37)	34.82 (0.29)	29.77 (0.53)	34.42 (0.31)	34.22 (0.32)
Mean VIF	1.99	2.09	1.90	2.13	1.99	2.07	1.90	2.11
Conditional number	19.01	19.55	27.59	23.11	16.99	7.38	26.23	11.88

Notes: Two step robust specification has been used. Robust *t*-statistics in absolute value are reported in parenthesis. (**), (***) Significant *p*-value at the 5%, 1%, respectively. AR(1) and AR(2) are tests-with distribution $N(0, 1)$-on the serial correlation of residuals. Sargan Chi-square test for over identification of restrictions. Mean VIF and Condition number test for multicollinearity robustness.

green exports as it is correlated to competitiveness actions and contributes along with innovation to economic success. Recalling that PACE mainly consist of investment in end of pipe options to reduce environmental impact, they may well act as a demand-side driver in a typical lead-users market approach.

6. Conclusions

We have shown that evidence in support of the strong and narrowly strong Porter hypothesis can be found for the EU15 over the decade 1996–2007, since environmental policy actions seem to foster export dynamics rather than undermine EU competitiveness in international markets.

Divergent effects played by different policies are ascertained, demonstrating that the PH is not to be taken for granted and it is sector-specific, as well as policy instrument-specific. Overall, the picture is nevertheless largely in favour of positive effects of environmental policies on the EU competitiveness.

With regard to the strong PH tested here, we provide original results by disaggregating effects across manufacturing sectors and exploiting diverse innovation and policy related drivers. Overall, the effect of environmental taxes does not conflict with export performances, while in some cases they give a large impulse to export dynamics. In particular, the high tech sector is the one that responds more positively to energy and environmental taxation whereas the more energy intensive medium tech and low technology sectors are not negatively impacted.

Our results on the narrowly strong PH seem to confirm the possibility of a green competitiveness strategy for the EU, coherently with recent European Union efforts towards a stronger integration between environmental strategies and innovation efforts as expressed by the Decision to meet the Community's greenhouse gas emission reduction commitments up to 2020 following the so-called 20–20–20 Strategy given by the decision no.406/2009 (EC, 2009) and the EU Strategic Energy Technology Plan (SET Plan, COM(2007) 723).

Overall, the relative weight of public and private levers for environmental protection is quite strong, but exports competitiveness seems to benefit the most when the regulatory framework is well followed by private innovation efforts. An important result emerging from this analysis is that innovation intensity shows positive and robust effects over export competitiveness across the whole technological ladder, with a stronger impact on higher technology sectors.

These results seem to be very good news. Such interventions, that may be structured in different ways according to different environmental policy strategies, do not bring about indirect costs through depressed economic performance, at least on the export component. On this basis, it becomes more likely that environmental and regulatory pressures increase their social acceptability provided that the sum of social benefits caused by environmental damage reductions minus compliance costs (tax burden, compliance costs and innovation investments) is going to be positive. The likelihood of such a success story increases with a stronger coordination between environmental and innovation actions.

Following these results, future research efforts should be directed towards investigating the effective role of environmental policies in inducing leading firms in specific green technology sectors to increase their innovative efforts. To this purpose, two complementary research approaches should be implemented: on the one side by working more deeply on patents classification in order to link innovation output with R&D private efforts as provided by the new CIS wave; on the other side by observing diffusion paths of green technologies in order to better understand which are the main drivers transforming new inventions and technologies into economic opportunities for producing firms as well as environmental gains for the society as a whole.

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Appendix A.

Figs. A1 and A2.
Tables A1–A6.

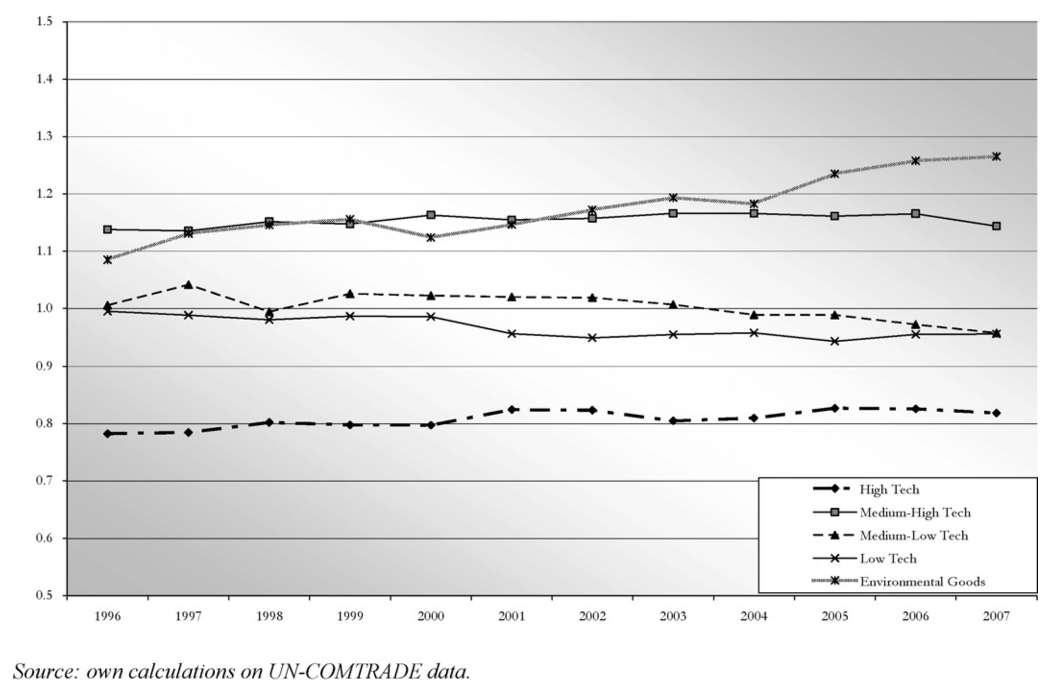
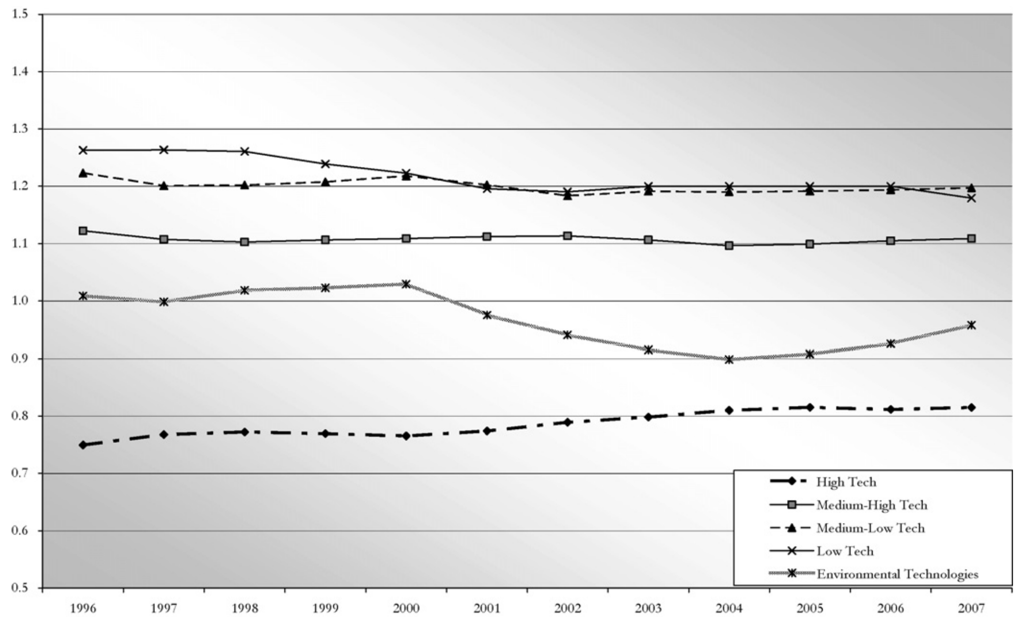


Fig. A1. RCA on exports by technology sectors and environmental goods (EU15).
Source: Own calculations on UN-COMTRADE data.



Source: own calculations on OECD-PATSTAT data.

Fig. A2. TRCA on patent stocks by technology sectors (EU15).

Source: Own calculations on OECD-PATSTAT data.

Table A1
Classification of industrial sectors and concordance with patent fields (strong PH).

Macro sector	Sector	ISIC Rev. 3	NACE	Patent fields[a]
High-technology industries (SEC-1)	1. Aircraft and spacecraft	353	35.3	43
	2. Pharmaceuticals	2423	24.4	13
	3. Office, accounting and computing machinery	30	30	28
	4. Radio, TV and communications equipment	32	32	34–36
	5. Medical, precision and optical instruments	33	33	37–41
Medium-high-technology industries (SEC-2)	6. Electrical machinery and apparatus	31	31	29–33
	7. Motor vehicles, trailers and semi-trailers	34	34	42
	8. Chemicals excluding pharmaceuticals	24 excl. 2423	24 excl. 24.4	10–16
	9. Railroad equipment and transport equipment	352 + 359	35.2–35.4–35.5	44
	10. Machinery and equipment, others	29	29	21–27
Medium-low-technology industries (SEC-3)	11. Building and repairing of ships and boats	351	35.1	45
	12. Rubber and plastics products	25	25	17
	13. Coke, refined petroleum products and nuclear fuel	23	23	09
	14. Other non-metallic mineral products	26	26	18
	15. Basic metals and fabricated metal products	27–28	27–28	19–20
Low-technology industries (SEC-4)	16. Manufacturing, others	36	36	46
	17. Wood, pulp, paper, paper prod., print and pub.	20–22	20–22	06–08
	18. Food products, beverages and tobacco	15–16	15–16	01–02
	19. Textiles, textile products, leather and footwear	17–19	17–19	03–05

[a] The figures reported in column "Patent fields" refer to the 46 fields where patents are classified by using the full list of IPC codes for each patent field described in the appendix of Schmoch et al. (2003) in order to provide a correspondence between IPC codes and ISIC Rev.3 industrial sectors.

Table A2
Classification of environmental goods export flows (narrowly strong PH).

A. Pollution management	B. Cleaner technologies and products	C. Resources management group
1. Air pollution control	1. Cleaner/resource efficient technologies and processes	1. Indoor air pollution control
1.1 Air-handling equipment	2. Cleaner/resource efficient products	2. Water supply
1.2 Catalytic converters		2.1 Potable water treatment
1.3 Chemical recovery systems		2.2 Water purification systems
1.4 Dust collectors		2.3 Potable water supply and distribution
1.5 Separators/precipitators		3. Recycled materials
1.6 Incinerators, scrubbers		3.1 Recycled paper
1.7 Odour control equipment		3.2 Other recycled products
2. Wastewater management		4. Renewable energy plant
2.1 Aeration systems		4.1 Solar
2.2 Chemical recovery systems		4.2 Wind
2.3 Biological recovery systems		4.3 Tidal
2.4 Gravity sedimentation systems		4.4 Geothermal

Table A2 (*Continued*)

A. Pollution management	B. Cleaner technologies and products	C. Resources management group
2.5 Oil/water separation systems		4.5 Other
2.6 Screens/strainers		5. Heat/energy savings and management
2.7 Sewage treatment		6. Sustainable agriculture and fisheries
2.8 Water pollution control, wastewater reuse equipment		7. Sustainable forestry
2.9 Water handling goods and equipment		8. Natural risk management
3. Solid waste management		9. Eco-tourism
3.1 Hazardous waste storage and treatment equipment		10. Other
3.2 Waste collection equipment		
3.3 Waste disposal equipment		
3.4 Waste handling equipment		
3.5 Waste separation equipment		
3.6 Recycling equipment		
3.7 Incineration equipment		
4. Remediation and cleanup		
4.1 Absorbents		
4.2 Cleanup		
4.3 Water treatment equipment		
5. Noise and vibration abatement		
5.1 Mufflers/silencers		
5.2 Noise deadening material		
5.3 Vibration control systems		
5.4 Highway barriers		
6. Environmental monitoring, analysis and assessment		
6.1 Measuring and monitoring equipment		
6.2 Sampling systems		
6.3 Process and control equipment		
6.4 Data acquisition equipment		
6.5 Other instruments/machines		

Table A3
Classification of environmental technologies an IPC codes (narrowly strong PH).

Technological domain	IPC code
Pollution abatement and waste management	
Air pollution abatement	
Filters or filtering processes specially modified for separating dispersed particles from gases or vapours	B01D46
Separating dispersed particles from gases, air or vapours by liquid as separating agent	B01D47
Separating dispersed particles from gases, air or vapours by other methods	B01D49
Combinations of devices for separating particles from gases or vapours	B01D50
Auxiliary pre-treatment of gases or vapours to be cleaned from dispersed particles	B01D51
Chemical or biological purification of waste gases	B01D53/34–36
Removing components of defined structure; Sulphur compounds	B01D53/48–52
Removing components of defined structure; nitrogen compounds	B01D53/54–58
Removing components of defined structure; simultaneously removing sulphur oxides and nitrogen oxides	B01D53/60
Removing components of defined structure; carbon oxides	B01D53/62
Removing components of defined structure; heavy metals or compounds thereof, e.g., mercury	B01D53/64
Removing components of defined structure; ozone	B01D53/66
Removing components of defined structure; halogens or halogen compounds	B01D53/68–70
Removing components of defined structure; organic compounds not provided for – e.g. hydrocarbons	B01D53/72
Separating dispersed particles from gases or vapour, e.g., air, by electrostatic effect	B03C3
Use of additives to fuels or fires for particular purposes for reducing smoke development	C10L10/02
Use of additives to fuels or fires for particular purposes for facilitating soot removal	C10L10/06
Blast furnaces; Dust arresters	C21B7/22
Manufacture of carbon steel, e.g. plain mild steel, medium carbon steel, or cast-steel; removal of waste gases or, etc.	C21C5/38
Exhaust or silencing apparatus having means for purifying, rendering innocuous, or otherwise treating exhaust, etc.	F01N3
Exhaust or silencing apparatus combined or associated with devices profiting by exhaust energy	F01N5
Exhaust or silencing apparatus, or parts thereof	F01N7
Electrical control of exhaust gas treating apparatus	F01N9
Monitoring or diagnostic devices for exhaust-gas treatment apparatus	F01N11
Combustion apparatus characterized by means for returning flue gases to the combustion chamber or, etc.	F23B80
Combustion apparatus characterized by arrangements for returning combustion products or flue gases to, etc.	F23C9
Arrangements of devices for treating smoke or fumes of purifiers, e.g. for removing noxious material	F23J15
Shaft or like vertical or substantially vertical furnaces; Arrangements of dust collectors	F27B1/18
Alarms responsive to a single specified undesired or abnormal condition and not otherwise provided for, e.g. Pollution	G08B21/12
Alarms responsive to a single specified undesired or abnormal condition and not otherwise provided for toxics	G08B21/14
Incinerators or other apparatus specially adapted for consuming specific waste or low grade fuels; of waste gases etc.	F23G7/06
Water pollution abatement (water and wastewater treatment)	
Arrangements of installations for treating waste-water or sewage	B63J4
Treatment of water, waste water, or sewage	C02F1
Biological treatment of water, waste water, or sewage	C02F3
Aeration of stretches of water	C02F7
Multistep treatment of water, waste water or sewage	C02F9
Treatment of sludge	C02F11
Fertilisers from waste water, sewage sludge, sea slime, ooze or similar masses	C05F7
Chemistry; Materials for treating liquid pollutants, e.g. oil, gasoline, fat	C09K3/32
Devices for cleaning or keeping clear the surface of open water from oil or like floating materials by separating etc.	E02B15/04
Cleaning or keeping clear the surface of open water; Barriers etc.	E02B15/06

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Table A3 (*Continued*)

Cleaning or keeping clear the surface of open water; Devices for removing the material from the surface	E02B15/10
Methods or installations for obtaining or collecting drinking water or tap water; Rain, surface or groundwater	E03B3
Plumbing installations for waste water	E03C1/12
Sewers – cesspools	E03F
Solid waste management	
Animal feeding-stuffs from distillers' or brewers' waste	A23K1/06
Animal feeding-stuffs from waste products of dairy plant	A23K1/08
Animal feeding-stuffs from meat, fish, or bones; from kitchen waste	A23K1/10
Footwear made of rubber waste	A43B1/12
Heels or top-pieces made of rubber waste	A43B21/14
Medical or veterinary science; Disinfection or sterilising methods specially adapted for refuse	A61L11
Separating solid materials; General arrangement of separating plant specially adapted for refuse	B03B9/06
Disposal of solid waste	B09B
Reclamation of contamined soil	B09 C
Manufacture of articles from scrap or waste metal particles	B22F8
Sawing tools for saw mills, sawing machines, or sawing devices; Edge trimming saw blades or tools combined etc.	B27B33/20
Recovery of plastics or other constituents of waste material containing plastics	B29B17
Preparing material; Recycling the material	B29B7/66
Presses specially adapted for consolidating scrap metal or for compacting used cars	B30B9/32
Systematic disassembly of vehicles for recovery of salvageable components, e.g. for recycling	B62D67
Transporting; gathering or removal of domestic or like refuse	B65F
Stripping waste material from cores or formers, e.g. to permit their re-use	B65H73
Hydraulic cements from oil shales, residues or waste other than slag	C04B7/24–30
Calcium sulphate cements starting from phosphogypsum or from waste, e.g. purification products of smoke	C04B11/26
Use of agglomerated or waste materials or refuse as fillers for mortars, concrete or artificial stone; waste materials, etc.	C04B18/04–10
Clay-wares; waste materials or refuse	C04B33/132–138
Fertilisers from household or town refuse	C05F9
Recovery or working-up of waste materials	C08J11
Luminescent, e.g. electroluminescent, chemiluminescent, materials; recovery of luminescent materials	C09K11/01
Production of liquid hydrocarbon mixtures from rubber or rubber waste	C10G1/10
Solid fuels essentially based on materials of non-mineral origin; on sewage, house, or town refuse	C10L5/46
Solid fuels essentially based on materials of non-mineral origin; on industrial residues or waste materials	C10L5/48
Working-up used lubricants to recover useful products	C10M175
Working-up raw materials other than ores, e.g. scrap, to produce non-ferrous metals or compounds thereof, etc.	C22B7
Obtaining zinc or zinc oxide; from muffle furnace residues	C22B19/28
Obtaining zinc or zinc oxide; from metallic residues or scraps	C22B19/30
Obtaining tin; from scrap, especially tin scrap	C22B25/06
Mechanical treatment of natural fibrous or filamentary material to obtain fibres or filament; arrangements, etc.	D01B5/08
Textiles; disintegrating fibre-containing articles to obtain fibres for re-use	D01G11
Textiles; arrangements for removing, or disposing of noil or waste	D01G19/22
Paper-making; fibrous raw materials or their mechanical treatment; the raw material being waste paper or rags	D21B1/08–10
Paper-making; fibrous raw materials or their mechanical treatment; defibrating by other means of waste paper	D21B1/32
Paper-making; other processes for obtaining cellulose; working-up waste paper	D21C5/02
Paper-making; pulping; non-fibrous material added to the pulp; waste products	D21H17/01
Street cleaning; apparatus equipped with, or having provisions for equipping with, both elements for removal of refuse	E01H6
Street cleaning; removing undesirable matter, e.g. rubbish, from the land, not otherwise provided for	E01H15
Cremation furnaces; incineration of waste; incinerator constructions; details, accessories or control, etc.	F23G5
Cremation furnaces; incinerators or other apparatus specially adapted for consuming specific waste or low grade, etc.	F23G7
Renweable energy	
Wind power	
Wind motors	F03D
Solar energy	
Devices for producing mechanical power from solar energy	F03G6
Use of solar heat, e.g. solar heat collectors	F24J2
Drying solid materials or objects by processes involving the application of heat by radiation – e.g. from the sun	F26B3/28
Devices consisting of a plurality of semiconductor components sensitive to infra-red radiation, light-specially adapted	H01L27/142
Semiconductor devices sensitive to infra-red radiation, light, electromagnetic radiation of shorter wavelength, etc.	H01L31/042–058
Generators in which light radiation is directly converted into electrical energy	H02N6
Geothermal energy	
Devices for producing mechanical power from geothermal energy	F03G4
Production or use of heat, not derived from combustion-using geothermal heat	F24J3/08
Marine (ocean) energy	
Tide or wave power plants	E02B9/08
Submerged units incorporating electric generators or motors characterized by using wave or tide energy	F03B13/10–26
Ocean thermal energy conversion	F03G7/05
Hydro power	
Water-power plants; layout, construction or equipment, methods of, or apparatus for	E02B9
Machines or engines for liquids of reaction type; water wheels; power stations or aggregates of water-storage type, etc.	F03B3 or F03B7
Machine or engine aggregates in dams or the like; controlling machines or engines for liquids, etc.	F03B15
Biomass energy	
Solid fuels based on materials of non-mineral origin – animal or vegetable substances	C10L5/42–44
Engines or plants operating on gaseous fuels from solid fuel – e.g., wood	F02B43/08
Waste-to-energy	
Solid fuels based on materials of non-material origin – sewage, town, or house refuse; industrial residues or waste, etc.	C10L5/46–48
Incineration of waste – recuperation of heat	F23G5/46
Incinerators or other apparatus consuming waste – field organic waste	F23G7/10
Liquid carbonaceous fuels; gaseous fuels; solid fuels	C10L1 or C10L3 or C10L5
Dumping solid waste; destroying solid waste or transforming solid waste into something useful or harmless, etc.	B09B1 or B09B3

Table A3 (*Continued*)

Plants for converting heat or fluid energy into mechanical energy-use of waste heat; profiting from waste heat of	F01K27 or F02G5
Incineration of waste; incinerator constructions; incinerators or other apparatus specially adapted for consuming, etc.	F23G5 or F23G7
Energy-efficiency in buildings and lighting	
Insulation	
Insulation or other protection; elements or use of specified material for that purpose	E04B1/62
Heat, sound or noise insulation, absorption, or reflection; other building methods affording favourable thermal, etc.	E04B1/74–78
Insulating elements for both heat and sound	E04B1/88
Units comprising two or more parallel glass or like panes in spaced relationship, the panes being permanently, etc.	E06B3/66–677
Wing frames not characterized by the manner of movement, specially adapted for double glazing	E06B3/24
Insulation heating	
Hot-water central heating systems – in combination with systems for domestic hot-water supply	F24D3/08
Hot-water central heating systems – using heat pumps	F24D3/18
Hot-air central heating systems – using heat pumps	F24D5/12
Central heating systems using heat accumulated in storage masses – using heat pumps	F24D11/02
Other domestic- or space-heating systems – using heat pumps	F24D15/04
Domestic hot-water supply systems – using heat pumps	F24D17/02
Use of energy recovery systems in air conditioning, ventilation or screening	F24F12
Combined heating and refrigeration systems, e.g. operating alternately or simultaneously	F25B29
Heat pumps	F25B30
Lighting	
Gas- or vapour-discharge lamps (compact fluorescent lamp)	H01J61
Electroluminescent light sources (LED)	H05B33
Electric and hybrid motor vehicles	
Dynamic electric regenerative braking for vehicles	B60L7/10–20
Electric propulsion with power supply from force of nature, e.g. sun, wind	B60L8
Electric propulsion with power supplied within the vehicle	B60L11
Methods, circuits, or devices for controlling the traction – motor speed of electrically propelled vehicles	B60L15
Arrangement or mounting of electrical propulsion units	B60K1
Arrangement or mounting of plural diverse prime-movers for mutual or common propulsion, e.g. hybrid propulsion	B60K6
Arrangements in connection with power supply from force of nature, e.g. sun, wind	B60K16
Electric circuits for supply of electrical power to vehicle subsystems characterized by the use of electrical cells, etc.	B60R16/033
Arrangement of batteries in vehicles	B60R16/04
Supplying batteries to, or removing batteries from, vehicles	B60S5/06
Conjoint control of vehicle sub-units of different type or different function; including control of energy storage, etc.	B60W10/26
Conjoint control of vehicle sub-units of different type or different function; including control of fuel cells	B60W10/28
Control systems specially adapted for hybrid vehicles, i.e. vehicles having two or more prime movers of more, etc.	B60W20

Table A4
Definition of variables.

Variable in Tables for results (notation for Eq. (3) in parenthesis)	Definition	Source
Dependent variables		
Export$_{ijt}$ (x^k_{ijt})	*Strong PH*: Total export flows in current US$ from countries *i* to countries *j* at time *t*, for 4 manufacturing macro-sectors (high-tech; medium-high-tech; medium-low-tech; low-tech, as defined in Table A1) (*time variant, sector specific*) *Narrowly strong PH*: Total export flows in current US$ from countries *i* to countries *j* at time *t*, for the full list of environmental goods (classification in Table A2, full list of HS1996 codes in Steenblik, 2005) (*time variant, sector specific*)	UNCTAD-COMTRADE
Standard gravity		
Distance$_{ij}$ ($dist_{ij}$)	Bilateral geographic distances from countries *i* to countries *j* (*time invariant, sector invariant*)	CEPII
Mass$_{ijt}$ ($mass_{ijt}$)	$mass_{ijt} = \ln(GDP_{it} + GDP_{jt})$ (*time variant, sector invariant*)	World Bank WDI
Similarity$_{ijt}$ (sim_{ijt})	$sim_{ijt} = \ln[1 - \left\|((GDP_{it})/(GDP_{it} + GDP_{jt}))^2 - ((GDP_{jt})/(GDP_{it} + GDP_{jt}))^2\right\|]$ (*time variant, sector invariant*)	
Firms heterogeneity$_{ijt}$ ($fhet^k_{ijt}$)	Calculated as the predicted probability function from the first-stage probit estimation (*time variant, sector specific*) $\Phi(x_{ijt}) = \int_{-\infty}^{x} \phi(t)dt = (1/\sqrt{2\pi}) \int_{-\infty}^{x} e^{-t^2/2}dt$	Own calculations from first-stage probit regressions
Mills Ratio $_{ijt}$ ($mills^k_{ijt}$)	Calculated as the standard normal distribution function from the first-stage probit estimation (*time variant, sector specific*) $\phi(x_{ijt}) = (1/\sqrt{2\pi})e^{-1/2x^2}$	
Environmental measures: Public policies and private actions		
Energy tax$_{it}$ ($envreg_{i,t-q}$)	Energy tax revenues as percentage of total revenues (*time variant, sector invariant*)	EUROSTAT
Environment tax$_{it}$ ($envreg_{i,t-q}$)	Environmental tax revenues as percentage of total revenues(*time variant, sector invariant*)	
Pace$_{it}$ ($envreg_{i,t-q}$)	Pollution abatement and control expenditures as percentage of GDP (*time variant, sector invariant*)	
Emas$_{it}$ ($envreg_{i,t-q}$)	Number of Eco-Management and Audit Scheme initiatives by private firms as percentage of GDP (*time variant, sector invariant*)	
Public and private innovation measures		
Knowledge$_{iPAT}$ ($inn^k_{i,t-q}$)	$INN^k_{it} = \sum_{s=0}^{t} PAT^k_{is} e^{[-\beta_1(t-s)]}$ Stock of knowledge function calculated on patents number (*time variant, sector specific*, Table A1)	EPO, OECD-STAN and EUROSTAT
Knowledge$_{iPATenv}$ ($inn^k_{i,t-q}$)	$INN^k_{it} = \sum_{s=0}^{t} PAT^k_{is} e^{[-\beta_1(t-s)]}$ Stock of knowledge function calculated on patents number (*time variant, sector specific*, Table A3)	
Knowledge$_{iPATtot}$ ($inn_{i,t-q}$)	$INN_{it} = \sum_{k=1}^{n} \sum_{s=0}^{t} PAT^k_{is} e^{[-\beta_1(t-s)]}$ Stock of knowledge function calculated on total patents number (time variant, sector invariant, with k sectors defined by Table A1)	

Table A4 (*Continued*)

Variable in Tables for results (notation for Eq. (3) in parenthesis)	Definition	Source
Knowl$_{i\ R\&Dtot}$ ($inn_{i,t-q}$)	Gross expenditures for R&D as percentage of GDP (*time variant, sector invariant*)	
Knowl$_{R\&D\text{-}ENVit}$ ($inn^k_{i,t,-q}$)	Public environmental R&D efforts as percentage of GDP, defined by Eurostat as "general R&D expenditures by public institutions for environmental protection purposes (GBAORD by NABS 92)" (*time variant, sector specific*)	
Knowledge$_{jt}$ (inn_{jt})	Innovation capability of the importing country calculated as Eq. (6) (*time variant, sector invariant*)	World Bank WDI
Dummy variables		
Euro	Dummy variable = 1 when the Euro currency has been adopted in the European Monetary Union (from 2002)	
Ets	Dummy variable = 1 when the Emission Trading Scheme has entered into force in the European Union (from 2005)	

Table A5
Descriptive statistics.

Variable	No observation	Mean	S.D.	Min.	Max.
Mass$_{ijt}$	22,400	27.26	1.00	25.16	30.38
Similarity$_{ijt}$	22,400	−2.11	1.33	−7.23	−0.69
Knowledge$_{jt}$	21,798	−2.25	1.44	−8.27	−0.05
Energy tax$_{it}$	24,192	1.56	0.21	1.11	2.13
Environment tax$_{it}$	24,192	0.71	0.60	−0.45	2.04
Emas$_{it}$	23,328	−9.09	1.56	−13.64	−6.58
Pace$_{it}$	24,192	−1.05	0.52	−2.12	−0.03
Knowledge$_{R\&D\text{-}ENVit}$	24,192	−4.16	0.43	−4.61	−3.22
Knowledge$_{R\&Dit}$	21,024	0.49	0.52	−0.93	1.45
Knowledge$_{PAT\text{-}TOTit}$	22,176	−8.79	1.55	−13.54	−6.71
Knowledge$_{PAT\text{-}HT1it}$	24,192	5.97	1.89	0.00	9.42
Knowledge$_{PAT\text{-}HT2it}$	24,192	6.15	1.92	1.39	10.02
Knowledge$_{PAT\text{-}HT3it}$	24,192	5.30	1.82	0.55	8.71
Knowledge$_{PAT\text{-}HT4it}$	24,192	4.64	1.68	0.00	7.79
Knowledge$_{PAT\text{-}ENVit}$	24,192	4.64	1.64	0.00	7.98

Table A6
Correlation matrix.

	Mass$_{ijt}$	Similarity$_{ijt}$	Knowledge$_{jt}$	Energy tax$_{it}$	Environment tax$_{it}$	Emas$_{it}$	Pace$_{it}$
Similarity$_{ijt}$	−0.2198*						
Knowledge$_{jt}$	0.1972*	0.2812*					
Energy tax$_{it}$	0.1249*	−0.0999*	−0.1146*				
Environment tax$_{it}$	−0.4506*	0.2519*	0.0187*	−0.0276*			
Emas$_{it}$	−0.1137*	0.0776*	0.1198*	−0.0755*	−0.1735*		
Pace$_{it}$	−0.001	−0.0029	−0.0165*	0.1114*	−0.1159*	0.4129*	
Knowledge$_{R\&D\text{-}ENVit}$	0.2226*	−0.1349*	−0.0201*	0.0529*	−0.0564*	0.0847*	0.1433*
Knowledge$_{R\&Dit}$	0.0251*	−0.0124	0.0467*	−0.3146*	−0.1594*	0.3767*	0.1758*
Knowledge$_{iPAT\text{-}ENV}$	0.5392*	−0.2767*	0.1758*	−0.1992*	−0.3673*	0.2708*	0.2068*
Knowledge$_{PAT\text{-}TOTit}$	0.1850*	−0.0858*	0.1555*	−0.3846*	−0.1604*	0.3836*	0.2725*
Knowledge$_{PAT\text{-}HT1it}$	0.5332*	−0.2738*	0.1615*	−0.1849*	−0.3712*	0.1576*	0.1507*
Knowledge$_{PAT\text{-}HT2it}$	0.5715*	−0.3026*	0.1263*	−0.1447*	−0.4512*	0.1944*	0.2543*
Knowledge$_{PAT\text{-}HT3it}$	0.5680*	−0.2964*	0.1313*	−0.1774*	−0.4328*	0.2188*	0.2099*
Knowledge$_{PAT\text{-}HT4it}$	0.5674*	−0.2959*	0.1413*	−0.1708*	−0.4192*	0.2338*	0.2143*

	Knowledge$_{R\&D\text{-}ENVit}$	Knowledge$_{R\&Dit}$	Knowledge$_{PAT\text{-}TOTit}$	Knowledge$_{PAT\text{-}HT1it}$	Knowledge$_{PAT\text{-}HT2it}$	Knowledge$_{PAT\text{-}HT3it}$	Knowledge$_{iPAT\text{-}ENV}$
Knowledge$_{R\&Dit}$	0.2092*						
Knowledge$_{iPAT\text{-}ENV}$	0.2591*	0.6654*					
Knowledge$_{PAT\text{-}TOTit}$	0.1347*	0.8795*	0.8460*				
Knowledge$_{PAT\text{-}HT1it}$	0.1969*	0.6691*	0.9602*	0.8672*			
Knowledge$_{PAT\text{-}HT2it}$	0.2810*	0.6636*	0.9762*	0.8356*	0.9689*		
Knowledge$_{PAT\text{-}HT3it}$	0.2275*	0.6477*	0.9711*	0.8405*	0.9749*	0.9849*	
Knowledge$_{PAT\text{-}HT4it}$	0.2362*	0.6270*	0.9713*	0.8223*	0.9609*	0.9772*	0.9704*

Notes: Correlation values with * are significant at the 5% level.

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