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Is environmental innovation embedded within high-performance organisational changes? The role of human resource management and complementarity in green business strategies

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ABSTRACT

This paper investigates whether firms' joint implementation of organisational innovation and training may foster their adoption of environmental innovation (EI), and if this correlation falls within Porter Hypothesis (PH) framework. We study the relationship of complementarity between strategies of High Performance Work Practices (HPWP) and Human Resource Management (HRM) when EI adoption is the firms' objective, using an original dataset on 555 Italian industrial firms regarding EI, HPWP and HRM, coherent with the last CIS2006-2008 survey. Results show that sector specificity matter. The only case in which strict complementarity is observed in organisational change concerns CO_2 abatement, a relatively complex type of EI, but this is true only when the sample is restricted to more polluting (and regulated) sectors. This evidence is coherent with the Porter hypothesis: complementarity-related adoption of EI is an element of organisational change in firms that are subject to more stringent environmental regulations. Nevertheless, the fact that strict complementarity is not a diffuse factor behind the adoption of all environmental innovation indeed does not come as a surprise. At this stage in the development of green strategies, the share of eco-firms is still limited, even in advanced countries that are seeking tools for a new competitiveness. The full integration of EIs within the internal capabilities and firm's own assets is far from being reached, even in advanced and competitive industrial settings.

1. Introduction

Do firms' actions in organisation and training foster the adoption of environmental innovation? Are environmental strategies integrated with organisational changes aimed at increasing firms' performances?

These questions, which revolve around the issue of environmental innovation adoption, relate to an exhaustive definition of Environmental Innovation (EI).[1] In the MEI (Measuring EI) research project (Kemp and Pearson, 2007; Kemp, 2010), EI is defined as "the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organisation (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives"[2] (Kemp, 2010, p. 2).

The definition of EI is not limited to specific technologies; it also includes new organisational methods, products, services and knowledge-oriented innovations. Organisational methods are also closely linked to education and training and then to human capital formation within firms.

It is worth spending some words on the definition of organisational changes as we intend them here. The literature often adopts the term High Performance Workplace Practices (HPWP),[3] to define a set of organisational changes which can be thought of as drivers of

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[1] For further discussion on EI determinants see Mazzanti and Zoboli (2009a) and Kemp and Pontoglio (2011).

[2] Results of the MEI project can be found at http://www.merit.unu.edu/MEI/.

[3] A plethora of names has been assigned to the 'new organisational practices' according to the practices selected and to the perspective adopted in the different studies: e.g. High Performance Work Systems (Ramsay et al., 2000; Osterman,

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superior innovative or economic performances in the firm. Coupled with this set of practices that are related to changes in production organisation (e.g. autonomous or semi-autonomous teams, quality circles) and labour organisation (e.g. job rotation, multitasking, increased workers' responsibility), we take into account Human Resource Management (HRM) practices which are linked to the training activity sphere. The human capital embodied in employees becomes a fundamental resource since "innovating organisation benefits from a strong skill-base" (Leiponen, 2005, p. 304), which is able to sustain and to direct absorptive capacity. The importance of training activities[4] that help generate and accumulate skills and competencies complementary to HPWP becomes clear. HPWP and HRM practices, as intended here, are intertwined firm's components, which, in a process of co-evolution and adaptation (Van den Bergh and Stagl, 2003), influence each other and impact the firm's innovative performance. Indeed, when a firm undergoes organisational changes such as the introduction of HPWP, the employees can be asked to learn how to manage and how to behave in a new organisational environment. Reconfiguring the organisational system in a way that increases workforce involvement and skill base, through the implementation of complementary HPWP/HRM practices, may be functional to the creation of an environment that smoothly absorbs and exploits even more complex types of innovation.

The potential relationship between HPWP/HRM and EIs is focused on as a core issue by the scholars examining the development of the well-known Porter Hypothesis (PH) (Ambec and Barla, 2006; Ambec and Lanoie, 2008; Ambec et al., 2010; Jaffe et al., 1995; Jaffe and Palmer, 1997).

Some recent studies have tried to shed light on this issue in EI-related literature. Among others, we can quote Cole et al. (2008) and Bloom et al. (2010). The first assesses the role of foreign derived training on a sample of African firms' environmental performances, finding that foreign training of a firm's decision maker, not foreign ownership per se, does reduce fuel use. Bloom et al. (2010), instead, survey UK manufacturing firms to assess whether energy efficiency performance is influenced by various forms of HPWP and find mixed evidence: more general proxies of human capital management do not have an impact, while some others seem to decrease energy use. Various other papers find a positive effect of training on EI performances (Horbach, 2008; Horbach et al., 2011; Cainelli et al., 2011). Further, Kesidou and Demirel (2012) show for a sample of UK firms that organisational factors are important in determining eco innovation investment. Horbach et al. (2012) stress how organisational capabilities, among several other factors, have to be included among the determinants of eco innovation.

Notwithstanding the above, integration of environmental innovation studies and the stream of organisational change research is far from being fully satisfactory: research windows are open. In particular, we are not aware of studies that investigate the role of the HPWP/HRM couple in the specific theme of EI adoption[5] (Rennings, 2000).

The aim of the paper is to investigate these somewhat unexplored issues.

We scrutinise whether firms' HPWP and HRM integrated strategies can foster the adoption of EIs. More precisely, our main research focus is to examine if a relationship of complementarity exists among these practices when the adoption of EIs is the objective. We embed this analysis within the Porter Hypothesis framework. We test complementarity between strategies for all manufacturing firms and for the sub-sample of more polluting and consequentially more heavily regulated firms.

We believe that a full integration of EI in firms innovation strategies is possible and needed to evolve EI from 'green washing' or 'ancillary' strategies into a key issue in firms' redefinition of competitive advantages. Fostering green innovation strategies for growth through adequate policy interventions and studying the determinants of eco-innovation, is a central issue in the near future of developed countries (OECD, 2011; EIO, 2011).

Thus, our purpose is to investigate the extent to which environmental innovation is associated to human resource management (HRM) and organisational change (HPWP) implementation, by assessing their impact through the lens of complementarity theory (Milgrom and Roberts, 1990, 1995).

In particular we analyse whether the implementation of joint HRM and HPWP strategies in fostering the adoption of firms' EIs is more evident for manufacturing firms belonging to heavily environmental regulated sectors under many aspects such as CO_2, emissions and waste.[6] In fact, more stringent environmental standards might foster firms' adoption of training and organisational innovation, which in turn could lead to further environmental innovation. The conceptual framework is that of the Porter idea of firm competitive advantages that reside in the firm value chain, within which "Strategy is manifested in the way activities are *configured* and *linked together*" (Porter, 2010).[7] These 'links' are the complementarity we investigate.

To be more precise in terms of the ample Porter-related literature available (Costantini and Mazzanti, 2012), we focus here on the weak aspect of the PH. 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 maximising behaviour. Agents will be induced by new constraints to re-engineer and reorganise technology and organisation, to improve activity coordination and to align incentives for the purpose of meeting these constraints at a lower cost, resulting in more efficiency and increased productivity. This view is also compatible with a neo Schumpeterian approach, as the dynamics of innovation are linked and co-evolve with appropriability conditions and the generation of new economic performances (Dosi et al., 2006; Malerba, 2007).

We investigate the issue by using new and original data that covers 555 Italian firms belonging to environmentally regulated manufacturing sectors over the 2006–2008 period, the same time span covered by the last CIS. We thus assure potential comparability of results with CIS studies (see Horbach et al., 2012 for a recent analysis on Germany).[8] CIS based studies surveyed by Mairesse and Mohnen highlight how issues regarding environmental innovation have recently made their appearance (Mairesse and Mohnen, 2010). Moreover, to better explore the complementary

2006); High Involvement Management (Bryson et al., 2005a); High Commitment Management (Dorenbosch et al., 2005; Bryson et al., 2005b).

[4] For empirical evidence on the relations between training and firms' economic performance see Conti (2005) and Zwick (2004).

[5] Recently, only Pekovic (2011) has tried to merge environmental and HPWP/HRM perspectives through a study that exploits an employee-employer dataset on French firms. Environmental innovations are assumed to enhance high commitment HRM practices, encourage employee involvement and reshape work organisation. Results show that greener firms present more labour oriented strategies and this is ultimately beneficial for firm-specific performance.

[6] A few examples of stringent environmental standards are: the EU emission trading 2003 Directive; IPPC 2008 Directive on emissions abatement and environmental technology together with its 2010 revision; the EU waste Packaging Directives of 1994 and 2003.

[7] Taken from Michael Porter's lecture at the Montreal 2010 event 'Porter +20', organised by Sustainable Prosperity (the citation is in slide 4, where the role of HRM in the value chain is stressed).

[8] See, among others, Bocquet et al. (2004), Cozzarin and Percival (2006, 2008), Gomez and Vargas (2009) and Schmiedeberg (2008).

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relationship within PH framework, we deepen our analysis on a subset of firms belonging to the most polluting sectors, which are those most challenged by environmental regulations.

The paper is structured as follows: Section 2 presents the theoretical framework and lays out the main research hypotheses; Section 3 presents the survey and the original dataset; Section 4 shows the econometric analyses and complementarity tests; Section 5 concludes.

2. Environmental innovation and complementarity among HPWP/HRM practices: concepts and methods

What economists investigate through the analysis of complementarity is the extent to which different elements of strategy, structure and managerial processes in a firm fit with one another and generate higher performances. Ballot et al. (2011, p. 2) affirm: "the complementarities perspective is not itself a theory of organisational design, but rather an approach to help researchers to understand relational phenomena and how the relationships between parts of system create more value than individual elements of the system". Since the seminal applied work by Mohnen and Roller (2005), devoted to testing empirical evidence for complementarities in national innovation policies, great deal of the economic literature has revolved around the empirical analysis in order to test complementarities in firms' innovation practices.[9] In fact, firms' innovation activity is a complex outcome deriving from the influence of many factors that are interrelated through complementary relationships which might give "rise to systemic effects, with the whole being more than the sum of its parts" (Roberts, 2006, p. 37). Remaining within the innovation sphere, the importance of deepening empirical analysis of complementarity among different firms' training and organisational innovation strategies has already been explored. Galia and Legros (2004), for instance, in their analysis on complementarities between obstacles to innovation, highlight how innovation necessarily involves the combination of a skilled work force and adequate organisation. As concerns EI issues, we are not aware of studies that specifically analyse the relationship of complementarity among HPWP/HRM strategies.[11] 10

Recently, eminent scholars who have contributed to the environmental Porter Hypothesis (PH) debate (Ambec et al., 2010) have newly emphasised the role of competencies and training in achieving substantial adoption of environmental innovations, highlighting how a great part of these innovations (carbon reductions, closed material loops, recycling, etc.) call for *a full restructuring* of a firm's organisational strategy. The role of adopting integrated strategies of training and organisational innovation is particularly relevant in the increasing need to adopt integrated and more complex green strategies and not only "end of pipe" technology. CO_2 abatement is surely a more complex type of innovation for firms compared to mere cuts in emissions such as SO_x–NO_x. Various internal and external drivers (Horbach et al., 2012) are relevant to trigger decarbonisation. The costly process of business decarbonisation might be mitigated by the occurrence of complementarity which, for example, generates increasing returns to scale.

The well-known PH states that 'well designed' environmental regulations (e.g. economic instruments such carbon taxes and emission trading, but not only) can stimulate innovations that offset the costs of pursuing that standard and which enhance firms' productivity (Porter, 1991; Porter and van der Linde, 1995; Costantini and Mazzanti, 2012; Mazzanti and Zoboli, 2009b). This 'offset innovation effort' requires an often dramatic change in the way a firm approaches the management of its resources. It is of interest here that the basis upon which Porter relies is that of a systemic view of the firm. The systemic approach already adopted in the economic literature on innovation must necessarily be extended to environmental innovation. Moreover, the integration of practices such as HPWP/HRM into EI is coherent with an analysis of diffusion rather than patents. Patenting activity is also limited as a way to defend rents in economic-systems where the majority of firms are of small and medium size. Intangible ways of defining property rights are possibly more diffused and effective. We claim that the complementarity of assets is one of these, given its idiosyncratic properties and hard 'exportability' (Teece, 1996; Mancinelli and Mazzanti, 2009).

We are particularly interested in filling the gap existing in the analysis of the relationship between different forms of techno-organisational environmental innovations (such as CO_2 abatement, emission abatement, energy efficiency, EMS/ISO adoption) and HPWP/HRM strategies.

Since HPWP/HRM and innovation practices are typically investigated in discrete settings (e.g. adopting or not, adopting at an intensity higher than the average, etc.), we study complementarity between these forms of actions through the properties of supermodular functions. This technical approach has the benefit of focussing on a purely economic analysis, without the need to dwell on more mathematical issues, such as particular functional forms that ensure the existence of interior optima. For example, no divisibility or concavity assumptions are needed, so that increasing returns are easily encompassed.

Following Topkis (1995, 1998), Milgrom and Roberts (1990, 1995), Milgrom and Shannon (1994), we state that two variables x' and x'' in a *lattice*[11] X are complements if a real-valued function $F(x', x'')$ on the *lattice* X is supermodular in its arguments. That is, if and only if:

$$F(x' \vee x'') + F(x' \wedge x'') \geq F(x') + F(x'') \quad \forall x', x'' \in X. \tag{1}$$

Or, expressed differently:

$$F(x' \vee x'') - F(x') \geq F(x'') - F(x' \wedge x'') \quad \forall x', x'' \in X, \tag{2}$$

that is, the change in F from x' (or x'') to the maximum $(x' \vee x'')$ is greater than the change in F from the minimum $(x' \wedge x'')$ to x'' (or x'): raising one of the variables raises the value of increase in the second variable as well.[12] Supermodularity gives an analytical structure to the idea that "increasing the value of some variables never prevents one from increasing the others as well" (Milgrom and Roberts, 1995, p. 182).

In our specific case, we consider the 'Environmental Innovation function' of firm j (EI_j) as the firm's objective function and we focus

[9] Bloom et al. (2010) intuitively give emphasis to complementarity among management practices concerning human resources and organisational changes, but they do not report specific tests on any sort of definition for complementarity.

[10] More specifically, "a *lattice* $(X, \geq)$ is a set X with a partial order $\geq$ such that for any $x', x'' \in X$ the set X also contains a smallest element under the order that is larger than both x' and $x''(x' \vee x'')$ and a largest element under the order that is smaller than both $(x' \wedge x'')$" (Milgrom and Roberts, 1995, p. 181).

[11] From Eqs. (1) and (2) it is evident that complementarity is symmetric: increasing x' raises the value of increases in x''. Likewise, increasing x'' raises the value of increases in x'.

[12] The EU Emission Trading System (ETS), which followed a proposal for a Directive that had been discussed since 2001, was launched by the 2003 Directive. It is currently the major EU policy aimed towards achieving Kyoto and 202020 targets. It allocates tradable CO_2 permits to firms in sectors such as metallurgy, ceramics, paper and cardboard, chemical, coke and refinery as far as manufacturing is concerned. The latter two are not present in the Emilia-Romagna region. The innovation effects of (the EU) ETS (Ellerman et al., 2010), though have been extensively analysed and compared to other environmental policies at theoretical level, have not found so far a consolidated empirical testing, even in relation to the first pilot phase 2005–2007. Micro based studies on this issue are very rare.

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on two HPWP/HRM practices that can affect the firm's EI function, h' and h'':

$$EI_j = EI_j(h', h'', \theta_j) \quad \forall j. \tag{3}$$

The problem of firm j is to choose a combination of HPWP/HRM practices, $(h', h'') \in H$, which maximise its EI function. θ_j represents the firm's exogenous parameters. Actually, a firm operates in an environment which is characterised by exogenous parameters (such as the product market, specific sector technologies, sector-specific environmental policy) and one could be interested in how different values of the parameter θ may imply different instances of the firms' decisional problems and hence different firms' optimal choices concerning EI.

Complementarity between the two different practices of HPWP/HRM may be analysed by testing whether $EI_j = (h', h'', \theta_j)$ is supermodular in h' and in h''. Since each firm is characterised by specific exogenous parameters (θ_j), even if the maximisation problem is the same for all the firms, the *EI* function may result supermodular in h' and in h'' for some firms, but not for others.

Our aim is to derive a set of inequalities (such as those explicated in Eqs. (1) and (2)), that are tested in the empirical analysis.

More specifically, through the supermodularity approach we analyse whether the probability of a firm's adoption of EI is significantly influenced by the presence of complementarities among HPWP/HRM practices.

If in its EI maximising problem, a firm chooses to adopt neither of the two practices, namely $h' = 0$, $h'' = 0$, the element of the set $H$is $h' \wedge h''=\{00\}$ If a firm chooses to adopt both practices, we have $h' = 1$, $h'' = 1$ and the element of the set H is $h' \vee h''=\{11\}$ Including the mixed cases as well, we have four elements in the set H that form a lattice: $H = \{\{00\}, \{01\}, \{10\}, \{11\}\}$.

From the above we can assert that h' and h'' are complements and hence that the function EI_j is supermodular, if and only if:

$$EI_j(11, \theta_j) + EI_j(00, \theta_j) \geq EI_j(10, \theta_j) + EI_j(01, \theta_j), \tag{4}$$

or:

$$EI_j(11, \theta_j) - EI_j(00, \theta_j) \geq [EI_j(10, \theta_j) - EI_j(00, \theta_j)] + [EI_j(01, \theta_j) - EI_j(00, \theta_j)], \tag{5}$$

that is, changes in the firm's environmental innovation processes when both forms of HPWP/HRM practices are increased together are more than the changes resulting from the sum of the separate increases of the two kinds of practice. Actually, increases in *EI* due to an increase of both h' and h'' from {00} to {11} are greater (or at least equal) than the sum of increases in *EI* due to separate increases of h' and h'' from {00} to {10} ({01}).

To sum up, complementarity between the two decision variables (h' and h'') exists if the EI_j function is shown to be supermodular in these two variables and this happens when either inequality (4) or inequality (5) or other derived inequalities are satisfied.

It is worth highlighting what Milgrom and Roberts (1995) show (in their fourth and fifth results) that a firm's optimal choice related to a decisional factor may initially be zero. Nevertheless, if environmental change leads to an increase in the level of another variable (which has become more profitable), then the new optimal choice of the first variable may become positive if it shows a relationship of complementarity with the factor that has been increased. Thus, increasing both variables may become more attractive in a newly changed 'environment'. Hence the adoption of both complementary practices by a firm may be an optimal choice in some circumstances but not in others even if its behaviour is maximising in both cases.

'Environmental changes' may be represented as both dynamic and horizontal variations. In our analysis, which is static, we consider only the second type of variations and the parameter θ_j embodies the different environments that the different firms may face.

As it will become more clear in the following sections, for the scope of our analysis it is relevant to distinguish the situations in which the PH is more suitable. Indeed, our crucial question is if the joint implementation of HPWP/HRM strategies can foster the adoption of EIs especially in situations in which the PH can be verified, that is in situations of more stringent environmental regulations, namely for firms belonging to more polluting sectors, that, among other policies, have been subject to the EU ETS system since 2005.[13]

What our theoretical analysis suggests is that different HPWP/HRM strategies may result complements for some values of θ but not for others.

As an example, in our specific analysis firms operating in sectors less exposed to environmental regulations and hence, following the PH, less stimulated to adopt EIs, could find it more convenient to externalise the management of workforce training. This kind of behaviour could even lead to a crowding out effect among some of the many strategies of training and organisational innovation and hence to substitutability[14] among them.

We can thus set out two consequential research hypotheses:

[H1]. Complementarity that refers to HPWP/HRM strategies is relevant to fostering the adoption of various EIs (CO_2 abatement, emission abatement, EMS/ISO implementation, material use reduction).

[H2]. ETS firms belonging to sectors such as ceramics, metallurgy and paper cardboard might present more evident signals of complementarity than non-ETS firms as a way to pro-actively tackle the regulation challenge through 'innovation offsets'.

We test [H1] by taking all manufacturing firms into account, while we coherently test [H2] by taking only the more polluting manufacturing sectors into account.

It is finally worth noting that we are more interested here in examinations of two-three way relationships among individual elements of a firm's organisational changes, rather than investigations of 'entire' systems of complementarity.[15] Ennen and Richter assert that "complementarities are system specific phenomena. Studies of relationships among individual elements of factors can offer valuable insights, but the failure of such a study to confirm complementarity effects where it had been expected them may mean that the full range of factors at work and their relationships have not yet been fully understood" (Ennen and Richter, 2009, p. 3).

3. Data and empirical strategy

The empirical context of this work is the manufacturing sector of the Emilia-Romagna region in Italy (NUTS 2 level), which, with a population of around 4.5 million (ISTAT, 2010), accounts for 20% of national industrial production and about 9% of the national GDP. It is also one of the two most innovative regions (together with Lombardy) in the Italian context and it is classified as a medium-high

[13] A substitutability relationship exists if: $EI_j(11, \theta_j) - EI_j(00, \theta_j) \leq [EI_j(10, \theta_j) - EI_j(00, \theta_j)] + [EI_j(01, \theta_j) - EI_j(00, \theta_j)]$, that is, the changes in the firm's environmental innovation process are less when both forms of HPWP/HRM practices are increased together than the changes resulting from the sum of the separate increases of the two kinds of practice.

[14] See also Laursen (2002), Michie and Sheehan (2003) and Laursen and Foss (2003), for complementarities analyses entailing HRM practices defining HRM systems of practice.

[15] The consistency between the diffusion of EI in our sample and the data on EI from the Community Innovation Survey database covering 6483 Italian manufacturing firms, which shows adoption in a 13–18% range across sectors and type of EI is worth stressing. Adoptions in the northeast of Italy, where the region is located are 19% for energy efficiency and 15% for CO_2 abatement (and 18% and 14% respectively for Italy as a whole).

innovator region at the EU27 level (Brusco, 1982; Hollander et al., 2009). A leading innovative region of a developed country can represent a good ‘laboratory’ to test our hypothesis about HPWP/HRM complementary practices on EIs.

The test of research hypotheses [H1] and [H2] is based on micro level data coming from a unique dataset concerning a sample of 555 manufacturing firms located in the Emilia-Romagna region (see Appendix A for a snapshot of the questions used to construct the main variables). The information collected through a structured questionnaire refers to the 2006–2008 period. The sample is constructed on the basis of a stratified random sampling technique, in order to obtain reliable results for the overall regional manufacturing context, with a stratification by province (geographic location), size and sector (Table B1 in Appendix B). It is worth stressing again the proximity of our questions with those included in the CIS5 (Community Innovation Survey) carried out in 2008, which may allow for direct comparison with data collected at the European level on some specific issues. However, the information set provided by the questionnaire administered to firms' management is even richer than that drafted by the CIS and concerns several sets of firm activity, spanning across issues and themes such as technological and organisational changes, training activities, ICT implementation, environmental innovation and internationalisation strategies, as well as the quality of firm level industrial relations and working conditions, for which we focus on EIs and on HPWP/HRM practices in order to answer our research question as described below.

The parts of the questionnaire that we exploit in this paper are mainly those referring to EI adoptions and HPWP/HRM aspects.

3.1. EI variables

The outcome variables stem from a set of questions concerning the EI activities carried out by the firms in 2006–2008. EI is then neither sector nor technology specific and it can take place in any economic activity and not only in the still loosely defined ‘eco-industry’ sectors. It is not limited to environmentally motivated innovations, but includes the “unintended’ eco-effects of all innovations.

In formulating the questions relative to EIs we followed the MEI project (Kemp, 2010) that informed the CIS5. For this reason we elicited information (Table 1) concerning the adoption of EI for: the reduction of energy and material for unit of product (ENERGY), emissions reduction in terms of CO_2 (CO_2), emissions reduction to better the quality of soil, water and air (EMISSIONS) and, finally, the adoption of procedures such as EMAS, ISO14001 (EMASISO). EI is a key factor in tackling the challenge of sustainable development, namely but not only the challenges posed by the reduction of CO2 (set by Kyoto targets and the EU 2020 strategy) and waste reduction (Mazzanti and Zoboli, 2009c; Marin and Mazzanti, in press).

In Table 1 the distribution of EI in our sample is shown.[16] An expected result emerges when the overall sample is restricted to only those firms belonging to more polluting sectors[17]: the manufacture of coke, refined petroleum products and nuclear fuel; the manufacture of chemicals, chemical products and man-made fibres; the manufacture of other non-metallic mineral products and the manufacture of basic metals and fabricated metal products, which are respectively classified as DF, DG, DJ, DI (Table B1 in Appendix B) according to a two-digit NACE-Rev1 classification.[18] In fact, while the presence of EIs is really low in the overall sample, it gains several percentage points in distribution frequency when only the polluting sectors are considered, passing from an average of 14% to 20%.

Our analysis thus examines (i) the entire working sample of 555 firms and (ii) the sub-set composed of firms belonging to the most polluting sectors, which are those most challenged by environmental regulations (ETS *in primis*). In line with the outlined research hypotheses, our main aim is to investigate how the joint implementation of HPWP/HRM practices can foster the adoption of EIs firstly for all firms ([H1]) and secondly within the ‘Porter Hypothesis framework’ (see [H2]).

3.2. HPWP/HRM variables

Three sets of organisational aspects that can be brought back into the wider concept of HPWP/HRM practices are here taken into consideration (Table 2): changes in production organisation (ORGPROD), changes in labour organisation (ORGLAB) and training activities (TRAINCOVERAGE, TRAINCOMP, TRAININVEST). They represent a comprehensive set of organisational practices aimed at increasing firms' performances. These variables allow us to capture the within firms' strategic decisions belonging to the organisational sphere capable of increasing the absorptive capacity of the firm towards EIs.

Starting from the organisational changes set, the questions addressed to the management provided us with the possibility to construct composite additive indexes of intensity in organisational changes: the more organisational changes are implemented in both production and labour organisation, the higher the index. The items included in the indexes construction are associable to the set of items usually ascribed to HPWP practices in the literature, such as, for example, the introduction of team work and quality circles as for production organisation; and improvement of competences, increase of workers autonomy and problem solving, reduction of the hierarchical layer as regards labour organisation (see Appendix A). For purposes linked to the complementarity conceptual framework analysis, the indexes were dichotomised according to the following rule: if the index was above or equal to the mean (median) then we assigned the value 1, while otherwise we assigned the value 0. We note that the necessary dichotomisation of indexes and continuous variables is performed, to check the sensitivity of results, both using mean and median as statistics as clearly evidenced in section three below.

As for the training activities which refer to HRM practices, we exploit information concerning the percentage of employees covered by training programmes (TRAINCOVERAGE), a variable that tells us whether the firm introduced training courses in order to develop the entire range of competences (TRAINCOMP)[19] listed in the questionnaire (technical, IT, organisational and concerning economics/law) and not just some of them and finally, a variable that informs us whether the firm invested its own economic resources in training activities (TRAININVEST).

On the basis of such dichotomised HPWP/HRM variables we were able to define four states of the world, as it is shown in Table 3, where the distribution is reported. These are the ‘states’ we exploit for complementarity assessments as described in section two.

We may argue that the occurrence of the different states of the world associated to the joint presence/absence of pairwise

[16] Marin and Mazzanti (in press) present figures and trends for these sectors' emissions.

[17] Because of aggregation constraints regarding the collection of information in our survey we are forced to include the DH sector (Manufacture of rubber and plastic products) in the set of the polluting sectors.

[18] The variable takes value 1 only when the firms aim to develop all competences expressed in the question in Appendix A.

[19] We use such a taxonomy, instead of the two digit NACE REV1, in order to reduce the number of controls.

Table 1
Adoption of environmental-innovations (distribution).

	Whole sample		By more polluting sectors[a]	
	Freq.	%	Freq.	%
Energy/Material reduction per unit of product (**ENERGY**)	82	14.77	43	22.4
CO_2 reduction (**CO_2**)	64	11.53	33	17.19
Emissions reduction for soil, water and air (**EMISSIONS**)	78	14.05	41	21.35
Adoption of procedures like EMAS and ISO14001 (**EMASISO**)	80	14.41	36	18.75
Obs./mean %	555	13.69	192	19.92

[a] Two digit classification: DF, DG, DJ, DI (and DH).

Table 2
HPWP_D/HRM_D variables (distribution).

Variables (Dummies)	Whole sample		Polluting sectors[a]	
	Freq.	%	Freq.	%
HPWP				
Production organisation aspects (ORGPROD_D)	350	63.06	127	66.15
Labour organisation aspects (ORGLAB_D)	218	39.28	83	43.23
HRM				
Employees involved in training activities (TRAINCOVERAGE_D)	209	37.66	87	45.31
Full set of competences covered by training activities (TRAINCOMP_D)	58	10.45	18	9.38
Presence of resources invested in training (TRAININVEST_D)	408	73.51	153	79.69
Obs./mean%	555	40.23	192	44.40

[a] Two digit classification: DF, DG, DJ, DI (and DH).

Table 3
HPWP_D/HRM_D states of the distribution.

Variables (Dummies)		States of the world (555 obs.) whole sample %				States of the world (192 obs.) polluting sectors[a] %			
		(1,1)	(1,0)	(0,1)	(0,0)	(1,1)	(1,0)	(0,1)	(0,0)
TRAINCOVERAGE_D	ORGPROD_D	26.67	10.99	36.40	25.95	31.77	13.54	34.38	20.31
TRAINCOVERAGE_D	ORGLAB_D	21.44	16.22	17.84	44.50	27.08	18.23	16.15	38.54
TRAINCOMP_D	ORGPROD_D	8.47	1.98	54.59	34.95	7.81	1.56	58.33	32.29
TRAINCOMP_D	ORGLAB_D	7.57	2.88	31.71	57.84	6.25	3.13	36.98	53.65
TRAININVEST_D	ORGPROD_D	49.37	24.14	13.69	12.79	55.73	23.96	10.42	9.90
TRAININVEST_D	ORGLAB_D	32.97	40.54	6.31	20.18	36.46	43.23	6.77	13.54

[a] Two digit NACE-Rev1 classification: DF, DG, DJ, DI (and DH).

HPWP/HRM practices provides a first insight into the likely presence of complementarity (Mohnen and Roller, 2005). Let us consider the TRAINCOVERAGE_D and the two HPWP dummies (ORGPROD_D and ORGLAB_D). The occurrence of (1,1) plus (0,0) is greater than the occurrence of the sum of the other two states of the world, for both the whole sample and the polluting sectors sample. It is worth stressing that such a difference in occurrence is more evident for the polluting sectors, pointing, although in a descriptive way, to the presence of possibly stronger complementary relations between the couples of our HPWP/HRM variables. The same can be said when we take into consideration training investment dummy (TRAININVEST_D), while the nature of relations between the competencies addressed by training programmes and changes in labour and production organisation seems to be more oriented towards substitution rather than complementarity.

3.3. *Control variables*

To enrich the analysis and set a comprehensive vector of innovation related factors (Horbach et al., 2012) we use a standard set of controls, that includes size dummies, Pavitt/OECD taxonomy for sectors[20] and less standard aspects related to the firms' strategic behaviour such as the "openness" to international markets provided by a variable indicating if a firm is an associated company of a foreign one (INTERN_OPEN) and the type of such an association (e.g. joint venture, stake below or above 50%), the presence of resources invested in R&D (R&D) and an index capturing the intensity in collaborations for technological innovations (TECH_NET) (for descriptive statistics see Table B2 in Appendix B). The ratio behind the use of such variables is that they may constitute influencing structural and strategic factors for EI adoption: the openness to international markets as well as the effort devoted to R&D activities and to collaborations for technological innovations may represent positive impulses.

On the basis of the theoretical framework for complementarities assessment we set up a two steps procedure, described in the following section, in order to investigate the extent to which HRM and HPWP interact and eventually drive the adoption of EIs.

Our approach may by inscribed within a stream of works based on the direct utilisation of an objective function according to which we test the presence of complementary relationships among selected covariates (HPWP/HRM) over an objective variable (EI) (Mohnen and Roller, 2005). Such an approach differentiates from several others used to test the existence of complementarities, which usually do not need an objective variable, but are essentially based on 'revealed preferences' and are tested through correlations. The latter may be simple bivariate correlations or more sophisticated ones in which controls for observable and unobservables are made (see Athey and Stern, 1998; Arora, 1996 for a full review of the different approaches).

[20] Results are available upon request.

Unlike these approaches, here we set up an objective function, an innovation function, that can be modelled as follows:

$$[\mathrm{EI}]_i = b_{0i}[\mathrm{Controls}] + b_{1i}[\mathrm{HPWP\_D}(1),\quad \mathrm{HRM\_D}(1)] + b_{2i}[\mathrm{HPWP\_D}(1),\quad \mathrm{HRM\_D}(0)] + b_{3i}[\mathrm{HPWP\_D}(0),\quad \mathrm{HRM\_D}(1)] + b_{4i}[\mathrm{HPWP\_D}(0),\quad \mathrm{HRM\_D}(0)] + u_i \quad (7)$$

where the EI dummy variables enter a probit regression, the HPWP/HRM variables are capturing the different states of the world; it is worth noting that the constant term is suppressed in order to obtain coefficients for each state of the world; i stands for the *i-th* firm. Matching the HPWP/HRM factors generates six HPWP/HRM 'couples' that we include among the regressors for the four EI dependents (Tables C1 and C2 in Appendix C). In total we sum up to 24 cases in the analysis (6 states and 4 types of EI).

4. Empirical analysis

4.1. Probit regressions

The first step of the investigation is given by a set of probit regressions, that show the overall good quality of the model, in addition to both expected and unexpected signals. Both SIZE and TECH_NET matter in determining EI for the whole sample of firms (Table C1 in Appendix C), but when we look at the set of more polluting sectors (Table C2 in Appendix C), the significant relation with networking activities for innovation disappears. The dichotomous variables that identify the states of the world are all significant, although with a minus sign. We nevertheless note that those regressions are estimated with the omission of a constant. In a standard probit with the exclusion of one of the state of the world dummies and the reintegration of a constant term instead, the signs turn out to be more consistent with what we would expect: setting the state of the world (0,0) as a benchmark and omitted case, the state of the world (1,1) is significant and positive.[21]

Once we fitted the probit models,[22] the second step of the analysis was to test hypotheses implementing a set of *Wald tests*. The latter allows us to test the following linear restriction, under the null hypothesis, on the state-of-the-world-dummies coefficients: $b1 + b4 = b2 + b3$. The test, which is distributed as a χ^2 with one degree of freedom, since we are testing a single linear restriction at a time, is not informative as we would like. Indeed, we are interested in the following inequalities, namely the sign of the scalar linear combination of the coefficients of interest: $b1 + b4 - b2 - b3 \geq 0$; $b1 + b4 - b2 - b3 \leq 0$. The standard *Wald test* only informs us as to whether or not we can reject the null hypothesis of equality of the coefficients sum. However, coupling the information provided by the *Wald tests* with the sign of the inequalities, also confirmed by one-sided tests on the linear combination of the parameters, we know the direction towards which a rejection of the null leads us in terms of supermodularity or submodularity. If $b1 + b4 - b2 - b3 \geq 0$ and the *Wald test* leads us to reject the null, then we can argue that we are in presence of supermodularity and hence of complementary HPWP/HRM practices. Submodularity holds if $b1 + b4 - b2 - b3 \leq 0$ and the null is rejected as well.

[21] Innovation choices can be simultaneous. The empirical procedure may test dependence between environmental innovations. A set of bivariate probit models (setting up seemingly unrelated probit models) were created for this purpose. We then ran Wald tests accordingly for every couple of HPWP/HRM variables in each equation of the bivariate probit. Results, available upon request, mostly confirm the essence of probit analysis.

[22] As stated above, we also carried out one-sided tests, distributed as a standard normal Z, that give similar outcomes and from which the signs of our inequalities are confirmed.

We implement the set of tests on the coefficients associated to 24 cases. The complementarity hypothesis is also tested for the polluting/ETS sectors, following the same procedure and carrying out further 24 tests.

4.2. Complementarity analysis: all manufacturing sectors

In this section we scrutinise research hypothesis [H1].

Table 4 clearly shows that there are not cases of *strict complementarity*. [H1] is thus rejected. Overall, the investigation does support strict substitutability in one case. The critical value of the *Wald test*[23] (5% level of significance)[24] is surpassed for all cases of EI adoption for the couple 'TRAINCOMP-ORGPROD'.

The strong specificity of complementarity existence is then highlighted: training competencies – changes in re-organisation of production seem not to match well for the aim of increasing the adoption of EIs.

We note this is not in itself a 'failure': complementarity surely is an 'asset' that can improve firm performances, but trade-offs may simply illustrate that some firms are capable of managing one factor at a time. They cannot deal with complex organisational change, but they can positively correlate either training or organisational change with EI.[25]

This might also be coherent with recent evidence that shows how training (alone) is a determinant of EIs (Horbach, 2008; Cainelli et al., 2011). It is a signal of potential weaknesses and difficulty regarding the organisational change firms face. Further, Ennen and Richter (2009) state that (strict) complementarity can be a source of significant competitive advantage, but it is really idiosyncratic to the sector, innovation type and inputs to innovation or performance we analyse. The embeddedness in complex systems makes it hard for complementarity to be managed purposefully. Indeed, the two authors find that the evidence of (strict) substitutability among inputs, that is trade off in firm strategies, is quite diffused. Though the match of heterogeneous factors is more likely to generate complementarity gains, they did not find a single factor whose co-occurrence with others invariably results in the emergence of complementarity relationships.

Complementarities are not a low hanging fruit. They might exist as a content of new organisational designs and practices for some firms which maximise their innovation performance through the exploration of the full set of possibilities related to HRM/HPWP practices. This is a message that is useful for firms and managers in rethinking their processes.

Given that firms' heterogeneity is very relevant in the analysis of complementarities, we now analyse its presence for a specific subset of manufacturing firms.

4.3. Complementarity in a Porter framework: the more polluting sectors

As anticipated above we test the hypothesis [H2] for more polluting and regulated sectors. The heavier regulatory burden to

[23] The two tailed test on inequality has as a null hypothesis, depending on the direction of the inequality (≥; ≤) either 'complementarity' or 'substitutability'. This means that the non rejection of the null cannot allow an inference on the strong or weak content of these. The rejection of the null respectively means 'strong substitutability' and 'strong complementarity'. In other words, strong complementarity is assessable as a rejection of the null when testing substitutability. The two tests are obviously 'complements' and are based on the same t statistics.

[24] This is confirmed by simple probit regressions. Results available upon request.

[25] We also checked whether firms in the only sectors that have reduced emissions of CO_2 in the last 20 years behave differently. Results do not change with respect to those of 'polluting sectors' (sectors that have reduced emissions are DB–DC; DF–DH–DG, DJ).

Table 4
Complementarities tests in a discrete setting. Linear restriction on states of the world coefficients from probit regressions.[a]

HPWP_D/HRM_D variables (Mean value used for dicotomisation)		ECOINNO							
		ENERGY		CO_2		EMISSIONS		EMASISO	
		Wald test[b]	Sign of the linear combination $(b1+b4)+(-b2-b3)$	Wald test[b]	Sign of the linear combination $(b1+b4)+(-b2-b3)$	Wald test[b]	Sign of the linear combination $(b1+b4)+(-b2-b3)$	Wald test[b]	Sign of the linear combination $(b1+b4)+(-b2-b3)$
TRAINCOVERAGE_D	ORGPROD_D	0.01	≤0	0.31	≥0	0.1	≤0	0.34	≤0
TRAINCOVERAGE_D	ORGLAB_D	0.74	≥0	1.2	≥0	0.24	≥0	0.11	≥0
TRAINCOMP_D	ORGPROD_D	7.64***	≤0	8.00***	≤0	10.65***	≤0	7.13***	≤0
TRAINCOMP_D	ORGLAB_D	0.03	≥0	0.74	≤0	0	≤0	0.76	≥0
TRAININVEST_D	ORGPROD_D	0.35	≥0	0.28	≤0	0	≤0	2.12	≥0
TRAININVEST_D	ORGLAB_D	0.47	≥0	2.47	≥0	1.76	≥0	0	≥0

[a] Tests conducted on marginal effects provide the same results (not reported for space constraint but available from the authors upon request).
[b] Since we are testing one linear restriction at a time the Chi^2 distribution has 1 degree of freedom as the number of the linear restrictions. Critical values of $Chi^2(1)$ distribution: 6.63, 3.84 and 2.71 (***1%, **5% and *10% level of significance respectively); $N = 555$, $(b1+b4)+(-b2-b3) \geq 0$ is index of supermodularity. $(b1+b4)+(-b2-b3) \geq 0$ is index of submodularity.

Table 5
Complementarities tests in a discrete setting. Linear restriction on states of the world coefficients from probit regressions (Polluting sectors).[a]

HPWP_D/HRM_D variables (Mean value used for dicotomisation)		ECOINNO							
		ENERGY		CO_2		EMISSIONS		EMASISO	
		Wald test[b]	Sign of the linear combination $(b1+b4)+(-b2-b3)$	Wald test[b]	Sign of the linear combination $(b1+b4)+(-b2-b3)$	Wald test[b]	Sign of the linear combination $(b1+b4)+(-b2-b3)$	Wald test[b]	Sign of the linear combination $(b1+b4)+(-b2-b3)$
TRAINCOVERAGE_D	ORGPROD_D	0.41	≥0	4.15**	≥0	0.2	≥0	0.3	≥0
TRAINCOVERAGE_D	ORGLAB_D	1.03	≥0	0.48	≥0	0.34	≥0	1.89	≥0
TRAINCOMP_D	ORGPROD_D	0.44	≤0	1.83	≤0	1.89	≤0	0.25	≤0
TRAINCOMP_D	ORGLAB_D	0.06	≤0	0.28	≤0	0.02	≤0	0.51	≥0
TRAININVEST_D	ORGPROD_D	1.09	≥0	0.39	≥0	0.31	≥0	2.23	≥0
TRAININVEST_D	ORGLAB_D	0.4	≤0	n.f.	n.f.	2.01	≥0	0.02	≤0

[a] Tests conducted on marginal effects provide the same results (not reported for space constraint but available from the authors upon request); n.f. means the state of the world TrainInvest = 0 and OrgLab = 1 predict failures perfectly in the probit estimation, hence the variable is dropped and the test cannot be computed.
[b] Since we are testing one linear restriction at a time, the Chi^2 distribution has 1 degree of freedom as the number of the linear restrictions. Critical values of $Chi^2(1)$ distribution: 6.63, 3.84 and 2.71 (***1%, **5% and *10% level of significance respectively); $N = 555$, $(b1+b4)+(-b2-b3) \geq 0$ is index of supermodularity. $(b1+b4)+(-b2-b3) \geq 0$ is index of submodularity.

which more polluting sectors are subject might increase the importance of EI and the related likelihood of using complementarity based strategies to redesign organisation in the face of the regulation challenge.

The evidence in Table 5 is in fact somewhat different with respect to what we found in Table 4.

For this sub sample of firms belonging to sectors that are on the 'frontier' of environmental (climate change) challenges, the weakness regarding the linking of training competencies and organisation of production is not relevant.[26] As an example of quite different evidence, in one case (training coverage – organisation of production) we do find evidence in support of strict complementarity, at the 5% significance level. This shows that complementarity is present as an option in the firm HPWP/HRM tool kit to tackle the complex challenge of CO_2 abatement[27] It is worth noting that Italy is among those countries (we find a rare exception in Northern EU) that have not to cutting down on carbon dioxide. As evidence of the complexity of the challenge, Fig. 1 shows how the Italian industry has performed over the past decades. CO_2 emissions, whose reduction requires a full redefinition of economic, energy and technological strategies (clean integrated technologies), are

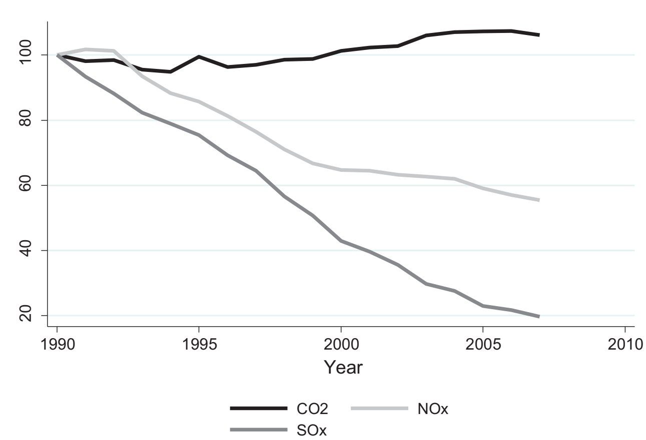

Fig. 1. Emissions and CO_2 trends in Italian economy, industry and services (1990 = 100).
Source: NAMEA, Italian Statistical Agency, environmental accounting datasets.

[26] If we use median values as a benchmark the result is confirmed. Results available upon request.
[27] If we use median values as a benchmark the result is confirmed. Results available upon request.

constant, while emissions, which are to a large extent dependent on filters, have been considerably cut. This poor picture also reflects innovation weaknesses. Heavier and more regulated sectors seem to react and adopt different strategies according to the PH.

Firms at the frontier of environmental challenges do respond differently than the average firm, though they still fail to exploit complementarities in extended ways.

As we recalled at the beginning, this is highly in the spirit of the Porter idea of competitive advantages stemming from the extension of the firm's aims and the use of multiple ways to reshape their organisation. It is then possible that properly designed regulations bring about conditions – such as boosting the demand for green products, pricing scarce resources – making unexploited technologies available (Wagner, 2006) and opening up the set of choices constrained by production habits towards a re-engineering of routines (Sinclair-Desgagnè, 1999).

We believe that the evidence around research hypothesis [H2], which shows that strict complementarity is present only in the CO_2 case[28] we commented on, is dependent upon the fact that most firms have tended to rely on single factors (training, cooperation with clients or universities, etc.) to adopt the environmental innovations they needed. This is well documented in EI literature. Nevertheless, this does not appear to be currently sufficient to increase the adoption of green innovations and enhance the possibility to witness EI as fully integrated strategies. Internal drivers, such as the reorganisation of firm production and HRM, are also needed for this purpose. EI adoption can thus become part of the asset stock possessed by firms which is constituted both by mere adoption and by the integration of EI with other competitiveness strategies (the complementarity intangible asset).

5. Conclusions

In the aim of providing new understanding about the effects of firms' organisational changes on EI adoption, we study the relationships between human resource management and internal processes of organisational change in labour and production through the lens of the complementarity theory. Though the relevance of HPWP/HRM for developing relatively new and complex forms of innovations such as EI has been noticed by scholars that contributed to the development of the Porter hypothesis, the lack of integration between environmental economics and HRM disciplines has blocked research in this specific realm.

We analyse diverse situations of potential complementarity between HRM and organisational changes, covering 4 different types of EI (CO_2 abatement, emissions reduction, EMS/ISO adoption, energy/material efficiency). We show that for EI adopted by firms located in a densely industrial region of the European Union which is highly exposed to international competition, strict complementarity is rarely present. In contrast, when looking at the full sample of manufacturing firms, strict substitutability emerges in one case. Training in key competencies and organisational changes in production seem to suffer from a mismatch when considering their integration which highlights how green strategies are not fully embedded within firms' reorganisation changes.

Though the fact that EI development in countries such as Italy is still in a non-mature phase might be part of the explanation for this, the evidence can signal 'problems'. We cannot say that observing substitutability is a weakness, given that EIs are possibly correlated to single factors. We note a lack of systemic innovation capability, which is one of the brakes behind the poor competitiveness and environmental performance of some (southern) EU countries at the moment.

The evidence confirms the well-known fact that complementarity is not to be taken for granted: it is industry, innovation and factor specific. Its achievement requires a full screening of firms' 'existent assets' and of those that could be 'created' (e.g. complementarity between assets as immaterial source of competitiveness). This requires proper investments in the re-engineering of firm organisation.

Firms that are on the frontier of environmental technological challenges (more polluting firms, more heavily regulated firms) instead present some evidence which does not reject the 'Porter hypothesis' and which we here enrich with complementarity concepts.

Complementarity emerges for CO_2 abatement, through the integration of training coverage and organisation of production strategies. Sector specificity, namely heavier environmental regulations, influences the way firms behave with respect to the setting up of complementarity strategies. We observe complementarity related adoption of EI as an element of organisational change in firms that are subject to more stringent regulations.

Nevertheless, the fact that strict complementarity is not a diffused factor behind the adoption of all environmental innovations comes in no way as a surprise. At this stage in the development of green strategies, the share of eco-firms is still limited even in advanced countries that are seeking for new competitive tools. Integration of EIs with the internal capabilities and firm's own assets is far from being achieved even in advanced and competitive industrial settings.

Further research should be aimed both at extending evidence to an EU level (through the CIS2008) and at assessing the effects of EI (among EIs and between EI and other techno-organisational changes) on economic and environmental firms' performance by also using a complementarity based perspective.

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Appendix A.

Selected questions used to construct our HPWP/HRM and EI variables. The answers refer to the period 2006–2008.

HPWP

Q1: Which of the following organisational practices do you adopt?

[28] We may argue that, for example, implementing organisational changes such as team working or quality circles and coupling them with wide training activities creates new knowledge and competencies that in turn foster the (absorptive) capacity to introduce energy saving practices.

n=	Production organisation practices (*x*)	Yes/No
1	Quality circles and/or improvement teams	
2	Team working	
3	Just-in-time	
4	Total quality management	

ORGPROD $= \frac{\sum_{n=1}^{4} x_n}{4}$ where *x* assumes value 1 if the organisational practice is marked with Yes; 0 otherwise

n=	Labour organisation practices (*z*)	Yes/No
1	Task rotation and/or job rotation (with tasks unchanged)	
2	Widening of the tasks and/or assignments	
3	Higher autonomy in performing tasks and assignments	
4	Broadening of competencies	
5	Training associated to organisational needs	
6	Higher autonomy in problem solving	
7	Structured discussion/confrontation on labour organisation and on quality of process/product	
8	Definition of goals for employees	
9	Employee performance evaluation systems	
10	Ex-*post* rewards based on the performance	
11	Ex-*ante* rewards in order to develop competencies	
12	Reduction of hierarchical layers within the same business section	
13	Techniques to manage information, knowledge and competency exchanges	

ORGLAB $= \frac{\sum_{n=1}^{13} z_n}{13}$ where *z* assumes value 1 if the organisational practice is marked with Yes; 0 otherwise

HRM

Q2: Please provide the percentage of permanent employees involved in training programmes:

Permanent employees	. . ..%

TRAINCOVERAGE = . . .%/100

Q3: Which kinds of competencies were addressed by training programmes?

Typologies of competencies	Yes/No
1. Computer science competencies	
2. Technical/specialised competencies	
3. Organisational/relational competencies	
4. Law/economic competencies	

TRAINCOMP = 1 if all the four types of competences are addressed; 0 otherwise

Q4: Did the firm invest its own resources in training programmes related to innovative activities? Yes/No

TRAININVEST = 1 if firms invested its own resources; 0 otherwise

ENVIRONMENTAL INNOVATION (EI)

Q5: Did the firms adopt "environmental" products and/or process technological innovations that induced the following benefits?

Benefits	Yes/No
1. Reduction in the use of materials and/or energy by output unit (including recycling)	
2. CO_2 emissions reduction	
3. Emission reductions that improve the quality of soil, water and air	

ENERGY = 1 if Reduction in the use of materials and/or energy by output unit (included recycling) marked as Yes; 0 otherwise

CO_2 = 1 if CO_2 emissions reduction marked as Yes; 0 otherwise

EMISSIONS = 1 if Emission reductions that improve the quality of soil, water and air; 0 otherwise

Q6: Does the firm have procedures that structurally identify its environmental performance?

Procedure	Yes/No
1. EMAS	
2. ISO 14001	
3. Others such as LCA, ISO14040, ...(specify)	

EMASISO = 1 if EMAS or ISO14001 or Others is marked as Yes; 0 otherwise

.

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Appendix B.

Table B1
Population and sample distribution (%) by sector and size.

Population distribution (%)	Size					
Sector (NACERev1)	20–49	50–99	100–249	250+	Total	Total (a.v.)
Food (DA)	5.65	1.94	1.16	0.64	9.39	382
Textile (DB–DC)	6.17	1.47	0.71	0.37	8.73	355
Wood, paper and other industries (DD–DD–DN)	7.79	1.67	0.79	0.42	10.67	434
Chemical and rubber (DF–DG–DH)	5.01	1.87	1.11	0.42	8.41	342
Non metallic mineral products (DI)	3.81	1.23	1.18	0.79	7.01	285
Metallurgy (DJ)	16.99	3.29	1.18	0.25	21.71	883
Machinery (DK–DL–DM)	21.44	6.37	4.06	2.24	34.10	1387
Total	66.86	17.85	10.18	5.11	100.00	
Total (a.v.)	2720	726	414	208		4068
Sample distribution (%)	**Size**					
Sector	20–49	50–99	100–249	250+	Total	Total (a.v.)
Food (DA)	2.88	3.78	1.62	0.54	8.83	49
Textile (DB–DC)	2.70	1.44	1.62	0.54	6.31	35
Wood, paper and other industries (DD–DD–DN)	3.60	2.88	1.08	0.90	8.47	47
Chemical and rubber (DF–DG–DH)	3.78	3.42	1.80	1.08	10.09	56
Non metallic mineral products (DI)	1.62	2.16	1.62	2.16	7.57	42
Metallurgy (DJ)	8.83	5.77	2.16	0.18	16.94	94
Machinery (DK–DL–DM)	14.05	15.32	7.39	5.05	41.80	232
Total	37.48	34.77	17.30	10.45	100.00	
Total (a.v.)	208	193	96	58		555

Table B2
Descriptive statistics.

	Whole sample			Polluting sectors		
	Mean (555 obs.)	StDev	Min/Max	Mean (192 obs.)	StDev	Min/Max
Outcome variables						
Energy/material reduction per unit of product (**ENERGY**)	0.147	0.355	0/1	0.223	0.417	0/1
CO_2 reduction (**CO_2**)	0.115	0.319	0/1	0.171	0.378	0/1
Emissions reduction for soil, water and air (**EMISSIONS**)	0.140	0.347	0/1	0.213	0.410	0/1
Adoption of procedures like EMAS and ISO14001 (**EMASISO**)	0.144	0.351	0/1	0.187	0.391	0/1
HPWP/HRM[a]						
Production organisation aspects (ORGPROD/HPWP)	0.484	0.329	0/1	0.474	0.342	0/1
Labour organisation aspects (ORGLAB/HPWP)	0.247	0.173	0/1	0.234	0.169	0/1
Employees involved in training activities (TRAINCOVERAGE/HRM)	0.378	0.369	0/1	0.428	0.393	0/1
Full set of competences covered by training activities (TRAINCOMP/HRM)	0.104	0.306	0/1	0.093	0.292	0/1
Presence of resources invested in training (TRAININVEST/HRM)	0.735	0.441	0/1	0.796	0.403	0/1
Controls						
Size dummies (5 Pavitt/OECD sector dummies: labour intensive (LI), resource intensive (RI), science based (SB), scale intensive (SI), specialised suppliers (SS))	–	–	0/1	–	–	0/1
Sector dummies (4 size dummies: 20–49 employees; 50–99 emp.; 100–249 emp.; more than 249 emp.)	–	–	0/1	–	–	0/1
INTERN_OPEN	0.021	0.066	0/0.83	0.016	0.053	0/0.33
R&D	0.800	0.400	0/1	0.776	0.417	0/1
TECH_NET	0.101	0.114	0/0.74	0.089	0.108	0/0.74

[a] Where appropriate we report the statistics of the indexes, since the distributions of the dichotomised variables are in the text.

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Appendix C.

Table C1
Probit results for all dependents (555 firms).

Sectors	ENERGY Yes	CO_2 Yes	EMISSIONS Yes	EMASISO Yes	ENERGY Yes	CO_2 Yes	EMISSIONS Yes	EMASISO Yes	ENERGY Yes	CO2 Yes	EMISSIONS Yes	EMASISO Yes
50–99 emp.	0.062	−0.005	−0.213	0.160	0.053	0.001	−0.192	0.172	0.141	0.047	−0.155	0.199
	(0.193)	(0.209)	(0.197)	(0.205)	(0.192)	(0.207)	(0.197)	(0.207)	(0.193)	(0.210)	(0.197)	(0.207)
100–249 emp.	0.359*	0.334	0.438**	0.758***	0.317	0.301	0.416**	0.742***	0.317	0.267	0.394*	0.702***
	(0.211)	(0.223)	(0.204)	(0.214)	(0.208)	(0.218)	(0.202)	(0.212)	(0.208)	(0.219)	(0.206)	(0.215)
>249 emp.	0.278	0.085	0.147	0.605**	0.284	0.129	0.174	0.631**	0.245	0.057	0.168	0.578**
	(0.249)	(0.266)	(0.246)	(0.249)	(0.250)	(0.274)	(0.249)	(0.253)	(0.253)	(0.270)	(0.250)	(0.254)
TECH_NET	1.797***	2.228***	2.087***	1.998***	1.879***	2.375***	2.242***	2.115***	1.986***	2.456***	2.357***	2.145***
	(0.646)	(0.658)	(0.630)	(0.634)	(0.635)	(0.655)	(0.624)	(0.633)	(0.628)	(0.653)	(0.618)	(0.607)
R&D	0.324	0.131	0.047	−0.268	0.430*	0.253	0.135	−0.189	0.376*	0.192	0.082	−0.230
	(0.229)	(0.235)	(0.203)	(0.196)	(0.221)	(0.229)	(0.204)	(0.196)	(0.227)	(0.234)	(0.202)	(0.194)
INTERN_OPEN	0.154	0.758	0.169	1.310	0.414	1.066	0.366	1.504	0.403	0.981	0.477	1.573
	(0.915)	(0.937)	(0.946)	(1.097)	(0.916)	(0.943)	(0.946)	(1.101)	(0.904)	(0.928)	(0.976)	(1.104)
STATES OF THE WORLD	TRAINCOV_D/ORGPROD_D				TRAINCOV_D/ORGLAB_D				TRAINCOMP_D/ORGPROD_D			
11	−1.237***	−1.361***	−1.035***	−1.249***	−1.383***	−1.582***	−1.204***	−1.373***	−1.736***	−2.026***	−1.881***	−1.737***
	(0.363)	(0.401)	(0.358)	(0.359)	(0.373)	(0.407)	(0.361)	(0.364)	(0.414)	(0.466)	(0.440)	(0.417)
10	−1.833***	−2.125***	−1.451***	−1.556***	−1.601***	−1.716***	−1.279***	−1.441***	−1.180**	−1.403***	−0.927**	−1.012**
	(0.412)	(0.444)	(0.401)	(0.398)	(0.364)	(0.395)	(0.369)	(0.378)	(0.500)	(0.538)	(0.473)	(0.462)
01	−1.794***	−1.930***	−1.529***	−1.674***	−2.066***	−2.332***	−1.815***	−1.906***	−1.691***	−1.845***	−1.434***	−1.563***
	(0.350)	(0.390)	(0.331)	(0.334)	(0.372)	(0.411)	(0.347)	(0.368)	(0.340)	(0.380)	(0.329)	(0.327)
00	−2.415***	−2.486***	−2.049***	−2.173***	−2.036***	−2.122***	−1.745***	−1.872***	−2.485***	−2.735***	−2.092***	−2.111***
	(0.374)	(0.439)	(0.369)	(0.372)	(0.348)	(0.392)	(0.335)	(0.334)	(0.380)	(0.427)	(0.378)	(0.373)
N	555	555	555	555	555	555	555	555	555	555	555	555
Chi^2	198.39	289.94	293.36	305.04	298.86	299.5	299.48	308.10	276.02	266.42	274.46	279.82
50–99 emp.	0.091	0.027	−0.175	0.182	0.035	−0.018	−0.204	0.112	0.034	−0.001	−0.191	0.127
	(0.188)	(0.202)	(0.193)	(0.205)	(0.191)	(0.206)	(0.192)	(0.205)	(0.190)	(0.202)	(0.191)	(0.203)
100–249 emp.	0.309	0.286	0.393*	0.711***	0.232	0.248	0.371*	0.628***	0.215	0.232	0.356*	0.625***
	(0.204)	(0.216)	(0.201)	(0.211)	(0.211)	(0.224)	(0.207)	(0.220)	(0.206)	(0.219)	(0.204)	(0.216)
>249 emp.	0.216	0.095	0.140	0.552**	0.156	0.016	0.100	0.471*	0.183	0.060	0.123	0.513**
	(0.245)	(0.266)	(0.243)	(0.251)	(0.246)	(0.263)	(0.244)	(0.250)	(0.243)	(0.265)	(0.245)	(0.250)
TECH_NET	1.947***	2.439***	2.356***	2.163***	1.835***	2.318***	2.197***	2.041***	1.834***	2.386***	2.250***	2.088***
	(0.626)	(0.628)	(0.613)	(0.628)	(0.615)	(0.632)	(0.618)	(0.618)	(0.610)	(0.627)	(0.615)	(0.620)
R&D	0.453**	0.268	0.168	−0.141	0.314	0.157	0.062	−0.269	0.394*	0.264	0.138	−0.208
	(0.223)	(0.232)	(0.204)	(0.198)	(0.229)	(0.236)	(0.204)	(0.197)	(0.224)	(0.235)	(0.208)	(0.200)
INTERN_OPEN	0.596	1.120	0.567	1.726	0.395	0.958	0.454	1.593	0.544	1.215	0.591	1.656
	(0.892)	(0.908)	(0.939)	(1.081)	(0.907)	(0.919)	(0.953)	(1.116)	(0.894)	(0.921)	(0.941)	(1.064)
STATES OF THE WORLD	TRAINCOMP_D/ORGPLAB_D				TRAININVEST_D/ORGPROD_D				TRAININVEST_D/ORGLAB_D			
11	−1.539***	−1.956***	−1.620***	−1.491***	−1.402***	−1.686***	−1.293***	−1.333***	−1.480***	−1.778***	−1.342***	−1.455***
	(0.411)	(0.464)	(0.418)	(0.407)	(0.345)	(0.384)	(0.338)	(0.348)	(0.354)	(0.401)	(0.351)	(0.355)
10	−1.837***	−1.705***	−1.765***	−2.022***	−2.046***	−2.301***	−1.766***	−1.844***	−1.727***	−1.974***	−1.548***	−1.584***
	(0.490)	(0.515)	(0.538)	(0.510)	(0.356)	(0.400)	(0.358)	(0.363)	(0.332)	(0.376)	(0.339)	(0.340)
01	−1.765***	−1.945***	−1.529***	−1.680***	−1.951***	−1.882***	−1.505***	−1.955***	−2.175***	−2.667***	−1.978***	−1.880***
	(0.347)	(0.379)	(0.331)	(0.340)	(0.380)	(0.396)	(0.339)	(0.351)	(0.496)	(0.524)	(0.447)	(0.434)
00	−1.977***	−2.113***	−1.687***	−1.780***	−2.348***	−2.760***	−1.981***	−1.902***	−2.121***	−2.062***	−1.623***	−1.996***
	(0.329)	(0.369)	(0.328)	(0.327)	(0.484)	(0.574)	(0.444)	(0.425)	(0.381)	(0.415)	(0.361)	(0.366)
N	555	555	555	555	555	555	555	555	555	555	555	555
Chi^2	285.51	297.88	296.33	295.70	275.4	274.81	293.13	297.70	269.84	292.11	296.31	294.28

Notes: ***1%, **5% and *10% level of significance respectively; standard errors in parenthesis.

Table C2
Probit results for all the dependents (polluting sectors: 192 firms).

Sectors	ENERGY No	CO_2 No	EMISSIONS No	EMASISO No	ENERGY No	CO_2 No	EMISSIONS No	EMASISO No	ENERGY No	CO_2 No	EMISSIONS No	EMASISO No
50–99 emp.	0.358	0.199	−0.081	0.495*	0.360	0.209	−0.047	0.508	0.286	0.085	−0.166	0.460
	(0.269)	(0.286)	(0.277)	(0.296)	(0.280)	(0.294)	(0.275)	(0.313)	(0.264)	(0.285)	(0.273)	(0.296)
100–249 emp.	0.769**	0.413	0.456	0.974***	0.778**	0.485	0.480	0.980***	0.601*	0.228	0.286	0.888***
	(0.321)	(0.342)	(0.315)	(0.345)	(0.322)	(0.341)	(0.312)	(0.346)	(0.310)	(0.331)	(0.311)	(0.332)
>249 emp.	0.948**	0.710*	0.549	1.224***	0.917**	0.684*	0.525	1.203***	0.736**	0.407	0.370	1.102***
	(0.383)	(0.391)	(0.380)	(0.395)	(0.388)	(0.398)	(0.381)	(0.403)	(0.368)	(0.384)	(0.374)	(0.387)
TECH_NET	0.066	0.652	0.131	0.306	0.349	1.016	0.404	0.467	0.536	1.107	0.754	0.563
	(0.977)	(0.996)	(0.951)	(0.979)	(0.980)	(0.991)	(0.956)	(0.991)	(1.037)	(1.066)	(1.039)	(1.012)
R&D	0.389	0.185	0.366	−0.002	0.463	0.198	0.462	0.056	0.369	0.114	0.358	−0.014
	(0.322)	(0.313)	(0.315)	(0.307)	(0.309)	(0.320)	(0.308)	(0.311)	(0.318)	(0.327)	(0.319)	(0.311)
INTERN_OPEN	0.412	1.116	−1.126	1.175	0.850	1.427	−0.790	1.634	0.793	1.328	−0.489	1.380
	(1.879)	(1.914)	(2.073)	(1.849)	(1.989)	(2.031)	(2.117)	(1.910)	(1.824)	(1.895)	(2.084)	(1.821)
STATES OF THE WORLD	TRAINCOV_D/ORGPROD_D				TRAINCOV_D/ORGLAB_D				TRAINCOMP_D/ORGPROD_D			
11	−1.006***	−0.910***	−0.815**	−1.191***	−1.309***	−1.349***	−1.118***	−1.338***	−1.329***	−1.300***	−1.599***	−1.388***
	(0.303)	(0.311)	(0.326)	(0.316)	(0.326)	(0.347)	(0.337)	(0.351)	(0.473)	(0.485)	(0.537)	(0.504)
10	−1.719***	−2.256***	−1.575***	−1.584***	−1.266***	−1.093***	−1.153***	−1.462***	−1.336	−0.867	−1.089	−1.214
	(0.407)	(0.508)	(0.471)	(0.392)	(0.320)	(0.335)	(0.359)	(0.341)	(0.824)	(0.855)	(0.834)	(0.857)
01	−1.679***	−1.643***	−1.279***	−1.600***	−2.262***	−2.196***	−1.716***	−2.118***	−1.273***	−1.096***	−0.964***	−1.364***
	(0.313)	(0.319)	(0.325)	(0.314)	(0.398)	(0.449)	(0.385)	(0.421)	(0.275)	(0.295)	(0.300)	(0.292)
00	−2.064***	−1.749***	−1.806***	−1.721***	−1.743***	−1.594***	−1.485***	−1.559***	−1.881***	−1.919***	−1.726***	−1.661***
	(0.403)	(0.427)	(0.412)	(0.397)	(0.285)	(0.318)	(0.299)	(0.309)	(0.319)	(0.404)	(0.376)	(0.329)
N	192	192	192	192	192	192	192	192	192	192	192	192
Chi^2	75.66	78.78	66	78.52	77.89	84.27	66.94	79.62	72.94	76.03	62.94	79.46
50–99 emp.	0.272	0.131	−0.137	0.513*	0.227	0.038	−0.114	0.428	0.199	0.119	−0.072	0.441
	(0.273)	(0.292)	(0.272)	(0.306)	(0.268)	(0.273)	(0.274)	(0.298)	(0.272)	(0.293)	(0.277)	(0.304)
100–249 emp.	0.633**	0.336	0.372	0.956***	0.547*	0.220	0.374	0.852**	0.538*	0.295	0.427	0.885**
	(0.315)	(0.344)	(0.313)	(0.338)	(0.323)	(0.344)	(0.321)	(0.347)	(0.321)	(0.346)	(0.315)	(0.345)
>249 emp.	0.758**	0.538	0.423	1.130***	0.708*	0.423	0.441	1.093***	0.662*	0.556	0.518	1.105***
	(0.373)	(0.389)	(0.371)	(0.398)	(0.366)	(0.376)	(0.371)	(0.388)	(0.372)	(0.412)	(0.384)	(0.396)
TECH_NET	0.645	1.197	0.765	0.702	0.379	0.813	0.377	0.444	0.686	1.057	0.489	0.667
	(1.035)	(1.052)	(1.023)	(1.065)	(1.017)	(1.042)	(1.009)	(1.022)	(1.023)	(1.027)	(0.996)	(1.027)
R&D	0.454	0.239	0.483	0.029	0.355	0.112	0.380	0.001	0.438	0.162	0.436	0.018
	(0.308)	(0.317)	(0.310)	(0.312)	(0.315)	(0.322)	(0.322)	(0.311)	(0.309)	(0.329)	(0.318)	(0.311)
INTERN_OPEN	0.955	1.502	−0.485	1.600	0.787	1.218	−0.795	1.468	1.050	1.747	−0.661	1.516
	(1.849)	(1.915)	(2.075)	(1.829)	(1.839)	(1.887)	(2.049)	(1.847)	(1.844)	(2.084)	(2.094)	(1.857)
STATES OF THE WORLD	TRAINCOMP_D/ORGPLAB_D				TRAININVEST_D/ORGPROD_D				TRAININVEST_D/ORGLAB_D			
11	−1.510***	−1.622***	−1.652***	−1.327**	−1.161***	−1.016***	−1.035***	−1.291***	−1.451***	−1.375***	−1.219***	−1.490***
	(0.519)	(0.562)	(0.549)	(0.543)	(0.299)	(0.306)	(0.337)	(0.308)	(0.336)	(0.348)	(0.353)	(0.354)
10	−1.318**	−1.067	−1.626**	−1.788***	−1.825***	−1.776***	−1.769***	−1.751***	−1.378***	−1.292***	−1.383***	−1.432***
	(0.658)	(0.652)	(0.746)	(0.651)	(0.343)	(0.367)	(0.416)	(0.331)	(0.274)	(0.279)	(0.317)	(0.273)
01	−1.533***	−1.547***	−1.256***	−1.610***	−1.631***	−1.438***	−1.113***	−1.871***	−1.520***	0.000	−1.853***	−1.552***
	(0.318)	(0.336)	(0.327)	(0.338)	(0.407)	(0.400)	(0.353)	(0.522)	(0.462)	(.)	(0.478)	(0.459)
00	−1.530***	−1.417***	−1.348***	−1.496***	−1.657***	−1.759***	−1.524***	−1.297***	−1.827***	−1.380***	−1.185***	−1.576***
	(0.250)	(0.272)	(0.282)	(0.274)	(0.426)	(0.574)	(0.461)	(0.410)	(0.397)	(0.394)	(0.351)	(0.442)
N	192	192	192	192	192	192	192	192	192	192	192	192
Chi^2	70.98	83.24	64.84	82.4	73.65	77.19	65.26	78.35	77.21	72.04	71.87	79.84

Notes: ***1%, **5% and *10% level of significance respectively; standard errors in parenthesis.

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