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ICT AND ENVIRONMENTAL INNOVATIONS IN A COMPLEMENTARY FASHION.

IS THE JOINT ADOPTION BY FIRMS ECONOMICALLY VISIBLE?

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Abstract

We analyse how the joint adoption of ICT practices and environmental innovation affect the labour productivity of firms. We study complementarity in innovation adoption, with respect to the specific research hypotheses that the higher the diffusion and radicalness of ICT and EI, the higher might firm's productivity be. As ICT are considered to be able to reduce the environmental footprint of different economics activities. We exploit original survey data which cover manufacturing firms for a dense SME area in the North-East of Italy (Emilia-Romagna region).We originally merge innovation survey data over 2006-2008 with firm's balance sheets over 2010-2011 to achieve this aim. The empirical evidence shows that for Emilia-Romagna manufacturing firms there are still wide margins for improving ICT-EIs integration in order to exploit their potential benefits on firm economic performance. However, the awareness of specific synergies seems to mainly characterize the heavy polluting firms, subject to ETS schemes, while for the remaining firms prevalently emerge some substitutability relations between ICT and EI. The latter firms are strategically less capable of exploiting the potential synergies between ICT and EI.

Keywords: ICT, environmental innovation, adoption, SME, polluting sectors, Porter hypothesis, complementarity, labor productivity

JEL: D22, L23, L25, L60, M15

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1. Introduction

There is empirical and theoretical evidence that innovation drives economic competitiveness and sustained long-term economic growth. Within the realm of innovative activity, environmental innovations (EIs) (Kemp, 1997; Kemp, 2010) are crucial to create synergies between sustainability and competitiveness towards the green economy (EEA, 2013, 2014). The role of innovation as a driver of long term productivity is a fact that goes back to the pillars of growth theory in economics, revitalised by the advent of sustainability policy oriented thinking that tries to synergically integrate the economy and the environment. Innovation and the complementarity between different innovations are key stones to create the pre-conditions for achieving and integrating social, economic, environmental goals by 2020 and in the longer run (Gilli et al., 2013, 2014).

Looking at other crucial innovation realms, the important role of Information and Communication Technologies (ICT) as an engine of growth in both developed and developing countries has increasingly been noticed, as shown by the commitments related to the European Digital Agenda[4] (Cardona et al., 2013). There is a large literature in economics that shows that ICTs are a major source of innovation and growth (see the review Kretschmer, 2012), and defines ICT as a General Purpose Technologies (GPT) that can be applied in different domains to enable further technological development and innovations.

There is an increased attention towards the effect of the development of ICT that reduces the environmental footprint of economic activities. ICTs have become essential to measure and model environmental processes, while also having an important role in improving the productivity of labour, capital and natural resources (Berkhout and Hertin, 2004). The optimisation of processes through ICTs is usually driven by the need to reduce costs, and in turn this also generates benefits for the environment. In this context, particular attention should be given to the dematerialization of economic activities. This is not only because of improvements in resource efficiency enabled through greater process control, but also because efficient processes tend to be relatively less polluting.

In the present article, we provide new micro evidence to the stream of literature which has scrutinized the effects of ICT on productivity - the well-known 'Solow Paradox', namely that the ICT diffusion is visible anywhere but in the specific effects on productivity[5] (Daveri, 2002). We here build up on two main streams of research – namely the consolidated literature on EI (drivers and especially effects of EI; Cainelli et al., 2011; Ghisetti and Rennings, 2014; Horbach et al.,

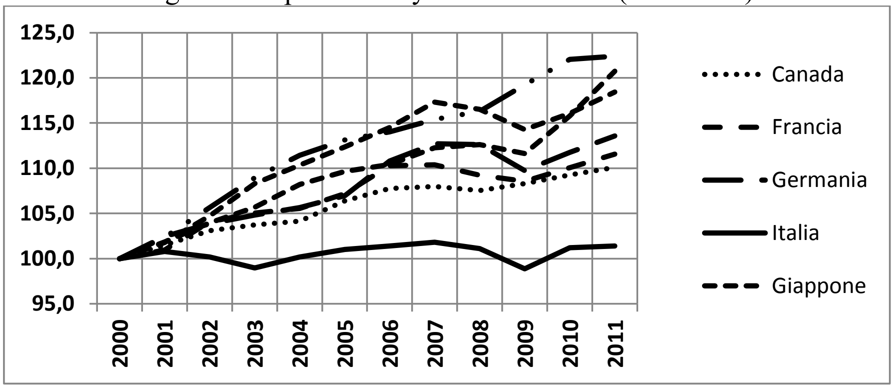
[4] European Commission official statement on the Digital Agenda 2010–2020, available at http://ec.europa.eu/information_society/newsroom/cf/pillar.cfm?pillar_id=46.
[5] See the special issue in Oxford review of economic policy, vol. 18, 2002.

2012) and that on ICT economic effects - to deliver a relatively new piece of evidence through the analysis of ICT complementarity in relation to the new wave of 'green oriented innovations'. Following the Porter idea of competitive advantages (Costantini and Mazzanti, 2012), the joint ICT/EI adoption can be an integrated innovation strategy to dematerialize/decarbonize the economic process while generating 'real' economic gains. The 'Green ICT' theme is thus addressed by looking at if and how firms behave in terms of new integrated technological adoptions. The literature on Green ICT shows that the adoption of ICT can permit to reduce the environmental footprint of economic activities. Researches on productivity paradox which has focused on the relationship between labor productivity and investment in ICT should also consider the links that exist between ICT and environmental resources/innovation (OECD, 2001).

Our empirical approach permits to investigate whether the joint adoption of ICT and green innovation affect the productivity of the firms and it permits also to disentangle the effect on heavy polluting and more regulated sectors within manufacturing. Sectoral differences have achieved a considerable consideration since the Pavitt taxonomy was introduced into the economics of innovation: science-based, specialized suppliers, supplier dominated and scale intensive firms. The categorization was based on sources and patterns of technological change. From a conceptual point of view, we may refer to the integrated concepts of sectoral and national systems of innovation which have consolidated in the innovation oriented evolutionary theory (Malerba, 2004) and have been exploited in the environmental economics literature looking at EIs and policy (Costantini and Mazzanti, 2012). The environmental regulatory pressure, in specific sectors, might increase the firm's incentive to find new technological solutions and tackle the policy challenge through the complementary adoption of innovations. ICT and EI are potentially the 'greener and smarter' choices in the innovation firm's toolkit. The question is whether they might drive competitiveness as well. If it is the case, they associate with enhanced economic-environmental sustainability.

In a context of enduring economic slowdown for the Italian economy, as the graphic on labour productivity shows (Fig.1), may be of extreme relevance to single out the micro-economic strategies that firms can implement in order to increase the labour force productivity. Italy is a key example of a relevant economy with still strong shares in manufacturing, that needs to re-enhance its economic performance through R&D investments and high value added innovation diffusion and adoption. A new positive path for the Italian economy would create the conditions for a more stable and sustainable Europe. It is worth noting that this economic trend is not different from the emission trend (e.g. CO_2), that highlights the synergy between economic and environmental dynamics (Marin and Mazzanti, 2013).

Fig.1 Labor productivity trend in the EU (2000=100)



Source: Our elaboration from OECD data

To test the hypothesis by which complementary adoption of ICT and EI backs higher labor productivity performances, the article analyses a well suited dataset collected in leading Italian region, Emilia-Romagna, which covers 555 manufacturing firms for which information on EI and techno-organisational innovations are available. This data has been merged with accounting variables collected in the dataset of the AIDA Bureau Van-Djik. The Emilia-Romagna is a Northern Italian region with a population of about 4.5 million people and a GDP (around 143 billion euro) that accounts for about 11% of the national GDP in 2011 (our elaboration on Eurostat – Regional Statistics Database).

The article is organised as follows. Section 2 reviews the existing literature on green ICTs, outlines the research questions and the hypotheses to be tested. Section 3 and 4 describe the data and the methodology respectively. Section 5 presents the empirical analysis. Conclusions and discussions follow.

2. Background literature and conceptual framework

The green growth is a major policy concern in both developed and in developing countries. In particular, ICT are a key enabler of green growth in different sectors of the economy (Ropke, 2012, Faucheux and Nicolaï, 2011). The digitalization of the economy has transformed business and society and represents an important engine of economic growth. Since ICT are GPT, they can have important environmental impacts on both manufacturers' production processes and the consumption patterns of users within a society (OECD, 2010). The potential impact of ICT in different sectors is raising attention on the direction of their development by increasing attention on direct and indirect environmental impacts (Mansell, 2012). It is reasonable to expect direct and indirect impacts of ICT on sustainable growth processes. Clearly these impacts will vary depending on the specific characteristics of countries and sectors and the type of innovation considered (whether it provides genuine novelty or simply enables incremental changes). Based on a sample of OECD countries, the article of Bassanin and Scarpetta (2002) shows that more advanced countries generally shared three economic characteristics: they have (i) improved the labour utilization combined with a generalized (ii) enhancement in human capital and they have (iii) invested more in ICT rather than in physical capital. It emerges that technological change embodied in new ICT capital goods has been a leading source of output and productivity growth in ICT-using sectors. Thus, it is interesting to see to what extent the use of ICT influences green growth.

In talking about "green ICT", it is important to distinguish between green ICT and ICT for green. On the one hand, there are ICT applications whose production entails better environmental performance than previous generations - usually referred to as "green ICT". On the other hand, there are ICT applications that can be used to improve environmental performance throughout the economy and society and which have an impact on the environmental productivity of other industries, particularly in terms of energy efficiency, waste management, and carbon footprint. These are usually referred to as "ICT for green" (OECD, 2011a).

Green ICT can be defined as ICT equipment, software and service that either reduce their own environmental impacts or the ones of other sectors of the economy and society. Those impacts can be any kind of pollution, the exhaustion of natural resources such as hydrocarbons or rare earth elements, or global changes in natural ecosystems such as global warming and biodiversity collapse.

Recent studies by the OECD (2010, 2011a) explicitly distinguish three types of green ICT and argue that the interaction between ICT and the environment can have three potential impacts: direct impacts (first order), enabling impacts (second order) and systemic impacts (third order). First order impacts involve ICTs providing better environmental performance than previous generations (*direct impacts*) of ICTs, implying that these technologies are constructed and designed to reduce their carbon footprint. The *enabling impact* includes all initiatives focusing on reducing environmental impacts by using ICT applications. One particular example is the dematerialization and substitution as advances in ICTs and other technologies facilitate the replacement of physical products and processes by digital products and processes. *Systemic impact* implies that progresses in ICTs and other technologies facilitate behavioral and organizational changes towards sustainability. These involve behavioral and non-technological factors. They include the intended and unintended consequences of wide application of green ICTs. Both the direct and systematic impacts can have also negative impact on the quest for sustainable activities, while the enabling effects have positive environmental impacts on the environment. In particular, first order impact entail the increase amount of use of ICT which in turn generate waste and the systematic effects might be source of the rebound effect.

For the purpose of our analysis, the enabling effect is extremely important as it permits to qualify the effect of ICT on green growth in terms of dematerialization of certain economic activities. Information technologies permit to enhance structural changes away from energy and material intensive production and more concentrates toward information intensive activities. ICT has contributed to change the way in which products and services are designed, produced and distributed. In other words, they permit a more intelligent use of resources. The enabling effect includes the intelligent production processes and designs, which permit to reduce the waste produced and to optimize the use of machinery in term of energy and resource consumption. Another important aspect of enabling effect of ICT is the reorganization of the supply chain and the organization of the business with entails the development of e-commerce or activities that can be completely digitalized such as the teleworking (Berkhout and Hertin, 2004). These kinds of ICT adoption and usage can permit to reduce the footprint of different economic activities.

3. Data

We exploit data from an original survey on a Northern Italian region, Emilia-Romagna. The survey was carried out in 2009 to cover the same basic questions on EI presented by the CIS (see Antonioli et al., 2013). The survey covers 555 manufacturing firms for which information on EI (Table A1 Appendix) and techno-organisational innovations are available. The ICT section is very detailed (see the questionnaire extracts in Appendix B) and provide many information that can be usefully correlated to EIs, which includes information on carbon abatement, emission abatement, EMS, environmental R&D, etc..[6]. The in depth information stemming from the survey is coupled with the second source of information: the AIDA Bureau Van-Djik dataset on firms balance sheets. The merge of the two sources of information allows us to test the potential complementarities among EIs and ICT adoption on the firm economic performance, measured as labour productivity per capita.

To the best of our knowledge, this is the first paper that treats and merges ICT and EI information at a relatively detailed level of analysis. This allows neater and more in depth insights on the correlation between ICT / EI (as separated and joint factors) and firm's productivity.

[6] See Antonioli et al. (2013) and Cainelli et al. (2012) for further information on the questionnaire data.

The information on ICT adoption are in fact extremely detailed[7] and offer a wide range of possibility to test complementarities among ICT and EIs (see the ICT variables used come from the questions Q3 and Q4 reported in Appendix B). At first we focused on the introduction of management systems and networking integration (ICTINTRO), constructed as the average number of practices introduced and then we concentrated on two specific systems: Material Requirements Planning (MRP) and Enterprise Resource Planning (ERP), which are more likely related to EI, because of their intrinsic nature of managerial systems to plan the use of materials and resources, than other types of ICT management systems. Secondly, we measure the use the firm does of ICT variables. The first variable (ICT_BS) informs us whether the firm uses ICT to manage the buy and sell processes; the second one tells whether the use of ICT supports product and process activities (ICT_PROD); the this whether ICT support cooperation activities (ICT_COOP) and, finally, the last one if the firm uses ICT to exchange information and services (ICT_SERV). This set of ICT variables permits to generate the above mentioned enabling impact in the economy as they permit to dematerialise the economic activities and improve the economic processes. As concerned the EIs, we construct a general measure of EI adoption: ECOINNO which indicates whether the firm has adopted any kind of eco innovation. We have also four binary detailed variables that inform us on the adoption of specific EIs: the variable ENERGY that capture the innovations addressed to reduce use of materials and/or energy by output unit (included recycling); the variable CO2, which informs us on the adoption of innovations addressed to reduce CO2 emissions; the variable EMISSIONS that takes value one if innovations addressed to reduce emissions for soil, water and air have been adopted; and finally, EMASISO variable, which is equal to one if procedure like EMAS and ISO14001 have been adopted.

The main descriptive statistics and the variables constructions are reported in tables A2 and A3 in Appendix.

4. Methodology

To address the research hypothesis of complementarity among EIs and ICT we estimate a consolidated productivity function using as covariates a set of variables pointed out as firm-level productivity determinants by previous works (Arvanitis, 2005; Giuri *et al*., 2008; Hall *et al*., 2012; Antonioli *et al*., 2010) through the following equation:

[7] As example, the EU CIS 2006-2008 survey that contains detailed information on EI only includes a very rough question on ICT adoption by firms.

$$(1)\quad [LABPROD]_{i,10\text{-}11} = a_0[Controls]_{i,06\text{-}08} + a_1[KEmp]_{i,06\text{-}08} + a_2[Export]_{i,06\text{-}08} + a_3[INNO]_{i,06\text{-}08} + a_4[EI]_{i,06\text{-}08} + a_5[ICT]_{i,06\text{-}08} + v_i$$

where LABPROD is a measure of labour productivity given by the ratio between value added and employment, the subscripts 06-08 and 10-11 represent the time spans in which variables are measured (2006-2008 and 2010-2011 respectively), *i* represents each firm. The covariates are standard controls such as size, sector and geographical dummies, a variable capturing the capital/technological intensity (KEmp), an export variable that proxy the firm openness toward international markets (Export), a set of innovation variables that capture the adoption of process (Proc) and product (Prod) innovation and the presence of training programmes for employees (Train) and, finally, the most important covariates for the present work: EIs and ICT variables. In order to get a first glimpse of the relation the EIs and ICT variables have with labour productivity we simply estimate equation (1) through OLS. Our estimation may suffer from endogeneity due to two main factors. The first one is related to the cross-sectional nature of our data, which does not allow us to fully control for reverse causality[8]: firms may self-select into EIs and ICT adoption as better performing firms may have higher financial and organizational capabilities for adopting both EIs and ICT. In order to mitigate this problem we exploit the diachronic structure of the dataset created thorough the merge of the cross-sectional survey and of the balance sheets panel: the dependent variable has a time lag of several years with respect to the covariates, being measured over the period 2010-2011, right after the big recession of the 2009, while the covariates are measured over the 2006-2008 period, right before the 2009. The time structure of our data allows us to exclude from our analysis the data of 2009, which are likely to be influenced by the strong exogenous shock given by the recession[9]. The second main factor causing endogeneity is given by the potential problem of relevant omitted variables. In order to address this issue we control for several observable characteristics, some of them capturing the managerial attitudes, a potential source of high heterogeneity in firm level studies.

Although the estimates from equation (1) can provide a first evidence on EIs and ICT relations with productivity, our aim is to test the existence of complementarities among EIs and ICT strategies that increase the gains in labour productivity. In order to test for complementarities we need to set up a different specification with respect to equation (1), which stems from the theories

[8] With this exercise, we are not able to identify clear causal relationship among variables, but robust correlations in a multivariate framework.

[9] Clearly we cannot purge our information from the recession influence, but at least we do not include in our estimation the information of the *annus horribilis* 2009 for the Italian and European economies.

and properties of supermodular functions (see Mohnen and Roller 2005; Antonioli et al, 2013 for a full mathematical clarification of the supermodular functions in testing complementarities). In the present case, and following Milgrom and Roberts (1995), we can say that two variables x' and x'' in a *lattice* 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:

(2) $$F(x' \vee x'') + F(x' \wedge x'') \geq F(x') + F(x'') \qquad \forall x', x'' \in X.$$

Or, written in a different way:

(3) $$F(x' \vee x'') - F(x') \geq F(x'') - F(x' \wedge x'') \qquad \forall x', x'' \in X,$$

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 increases in F of the second variable. In our case we consider the 'productivity function' of firm j ($LABPROD_j$) as the firm's objective function (see Antonioli et al., 2013; Mancinelli and Mazzanti, 2009 and Mazzanti and Zoboli, 2009 for more methodological details) as specified in equation (1), but substituting the EIs and ICT variables with quadruplets of states of the world for any given couple of EI and ICT. That is to say, the binary EI and ICT variables are interacted in order to create couples of innovation variables providing four states of the world for each couple: the firm may decide to adopt both innovations {1,1}, one but not the other {1,0} or {0,1} and neither one nor the other {0,0}. The specification of equation (1) is then:

(4) $[LABPROD]_{i,10\text{-}11} = a_0[Controls]_{i,06\text{-}08} + a_1[KEmp]_{i,06\text{-}08} + a_2[Export]_{i,06\text{-}08} + a_3[INNO]_{i,06\text{-}08} +$
+b1i[EI(1)/ ICT(1)] **+b2**i[EI (1)/ ICT (0)]+**b3**i[EI (0)/ ICT (1)] +**b4**i[EI (0)/ ICT (0)] + v_i

The set of the four states of the world represents a lattice $H = \{\{00\},\{01\},\{10\},\{11\}\}$ and the 'productivity function' is supermodular in the innovation couples, that is innovations are complements, if the following inequality is satisfied:

(5) $LABPROD_j(11,\Omega_j) - LABPROD_j(00,\Omega_j) \geq \left[LABPROD_j(10,\Omega_j) - LABPROD_j(00,\Omega_j)\right] +$
$+ \left[LABPROD_j(01,\Omega_j) - LABPROD_j(00,\Omega_j)\right]$

Where Ω_i is a vector of variables including *Controls*, *KEmp*, *Export* and *INNO,* that are thought to influence the labour productivity. The inequality shows that changes in the labour productivity when the innovations are increased together are higher than the changes resulting from the sum of the separate increases of the two innovations. Increases in $LABPROD$ due to an increase of both innovations from $\{00\}$ to $\{11\}$ are greater (or at least equal) than the sum of increases in $LABPROD$ due to separate increases of the innovations from $\{00\}$ to $\{10\}$ or $\{01\}$.

The operationalization of the procedure to test for the complementarities among innovations passes through the estimation of equation (4), in which all the four state of the world for each couple of innovations are included, in order to get the coefficients associated to each state of the world: b1 for $\{1,1\}$; b2 for $\{1,0\}$; b3 for $\{0,1\}$ and b4 for $\{0,0\}$. Then it is necessary to run several *Wald tests*. The latter allow 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 is distributed as an F statistic with one degree of freedom in the numerator, since we are testing a single linear restriction at a time, so we can apply the appropriate procedure for the p-value adjustment in testing inequalities[10]. Indeed, we are interested in the following inequalities, namely the sign of the scalar linear combination of our parameters of interest: b1+b4-b2-b3≥0; b1+b4-b2-b3≤0. If we amalgamate the information provided by the standard Wald test, by the adjusted p-values for inequality tests and by the sign of the linear combination of the coefficients we can state whether we are in presence of complementarity (b1+b4-b2-b3≥0) between a couple of two innovations or, instead, if we are in presence of substitutability (b1+b4-b2-b3≤0).

We apply the above procedure for both the whole sample of interviewed firms and for the subsample of most polluting ones, those subject to the Emission Trading Scheme (ETS)[11], which belong to the heavier sectors - and those not subject to the ETS scheme (NonETS) (see Tab.A2 in Appendix for a detailed distinction of the two sets of sectors). This strategy permits to disentangle the more pollutant and regulated sectors from the other.

[10] For an appropriate reference see http://www.stata.com/support/faqs/statistics/one-sided-tests-for-coefficients/.

[11] For detailed discussions on the main EU policy towards climate change, the EU emission trading system which has generated a price for carbon (currently around 5€ per tonne of carbon), we refer to Convery, 2009; Ellerman *et al*., 2010; Clò, 2008; Borghesi, 2011.

5. Results and discussion

The results of the empirical analyses (Tab.1) show that high levels of productivity are mainly associated with export and capital stock per capita, for the whole sample and for ETS firms and Non-ETS firms as well. Once we control for the latter variables for product and process innovations and the usual sector and size variables it emerges that EIs and ICT have no significant direct effect on productivity over the period 2010-2011. Similarly, their interaction (ICTIntro_d*ECOINNO) proves to be not significant in any estimations.

Tab 1: Results from OLS regressions: general ICT and EI covariates

	Whole Sample		ETS Sectors		Non ETS Sectors	
			LnVaEmp2010-2011			
Food	0.099	0.099			0.126*	0.124*
	(0.063)	(0.063)			(0.065)	(0.065)
Textile	-0.311***	-0.311***			-0.316***	-0.315***
	(0.063)	(0.063)			(0.066)	(0.066)
Shoes	-0.224***	-0.224***			-0.230***	-0.229***
	(0.082)	(0.082)			(0.085)	(0.085)
WoodRubbPlasOther	-0.362***	-0.362***			-0.345***	-0.345***
	(0.057)	(0.057)				
PaperPrinting	-0.237**	-0.237**	0.002	0.009		
	(0.114)	(0.114)	(0.113)	(0.114)		
CokeChemical	0.109*	0.108*	0.258***	0.265***		
	(0.061)	(0.062)	(0.072)	(0.074)		
NonMetallic	-0.158**	-0.158**	0.026	0.026		
	(0.070)	(0.070)	(0.080)	(0.079)		
Metallurgy	-0.197***	-0.198***				
	(0.040)	(0.040)				
20-49 emp.	-0.078	-0.077	-0.077	-0.089	-0.081	-0.075
	(0.050)	(0.050)	(0.090)	(0.088)	(0.058)	(0.058)
50-99 emp.	-0.033	-0.033	-0.072	-0.082	-0.006	-0.007
	(0.045)	(0.045)	(0.081)	(0.079)	(0.052)	(0.051)
100-249 emp.	-0.025	-0.025	0.017	-0.004	-0.044	-0.043
	(0.047)	(0.047)	(0.085)	(0.078)	(0.054)	(0.054)
KStockEmp0608	0.097***	0.097***	0.135***	0.135***	0.079***	0.080***
	(0.022)	(0.022)	(0.047)	(0.047)	(0.024)	(0.024)
CentralReg	0.044	0.044	-0.000	0.006	0.064*	0.064*
	(0.030)	(0.030)	(0.048)	(0.049)	(0.038)	(0.038)
Prod	-0.042	-0.042	-0.129**	-0.129**	0.004	0.004
	(0.034)	(0.034)	(0.063)	(0.063)	(0.039)	(0.039)
Proc	0.069*	0.069*	0.171**	0.168**	0.026	0.027
	(0.038)	(0.039)	(0.084)	(0.085)	(0.039)	(0.039)
Export	0.174***	0.175***	0.214*	0.204*	0.164**	0.164**
	(0.061)	(0.061)	(0.121)	(0.119)	(0.070)	(0.071)
Train_d	0.040	0.040	0.060	0.078	0.020	0.022
	(0.035)	(0.036)	(0.067)	(0.071)	(0.042)	(0.042)
ECOINNO	-0.021	-0.015	0.048	-0.007	-0.060	-0.021
	(0.035)	(0.046)	(0.050)	(0.056)	(0.050)	(0.083)
ICTIntro_d	-0.006	-0.003	-0.008	-0.056	-0.000	0.010
	(0.029)	(0.031)	(0.054)	(0.065)	(0.035)	(0.036)
ICTIntro_d*ECOINNO		-0.013		0.166		-0.064
		(0.072)		(0.121)		(0.105)
_cons	3.690***	3.688***	3.337***	3.347***	3.743***	3.732***
	(0.100)	(0.101)	(0.209)	(0.210)	(0.108)	(0.109)
N	555	555	183	183	372	372
AdjR2	0.294	0.292	0.301	0.305	0.293	0.292
F(d.f.)	16.219(19)	15.598(20)	9.071(14)	8.644(15)	13.408(15)	12.728(16)
p-value	0.000	0.000	0.000	0.000	0.000	0.000

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Because the results may depend on the ‘general’ nature of EIs and ICT variables, simply capturing the introduction of any kind of EI (ECOINNO) and of any kind of ICT based managerial system (ICT_INTRO) we also run a different specification, which includes more specific EIs and ICT terms (Tab.2). When we detail in such a way the covariates some more interesting results emerge. At first, it is interesting to notice that the introduction of EI to save energy (ENERGY) negatively relates to labour productivity for NonETS firms, while the opposite holds for EIs introduced to reduce CO_2 emissions. Heavier and more regulated ETS firms are unaffected by the specific adoption of EI and ICT. It is not completely unexpected: again, innovation effects on productivity, especially for some innovations, are not low hanging fruits. Various motives might be in place: the short time distance between innovation and observed economic performances, the effect of the 2009 recession which is between the innovation and the effects we observe, the inability by single innovations to produce real visible effects.

What we do note is a negative effect (non ETS firms) of energy efficiency innovations, which are costly in the short term. They may imply reallocation of investments and/or increases of specific labor force, both negatively impacting on productivity. The positive effect for CO2 innovations is worth being further investigated. We might observe that in the specific area we examine, key non ETS manufacturing sectors are ‘machinery’ and ‘food’. Those are historical specializations of the Region. Those manufacturing sectors might proactively lead climate change oriented investments due to their high exposure to international markets *and* strong relationships with the territory, two elements that might even matter more than regulations in some cases (Cainelli et al., 2012).

All in all, results confirm that for the whole sample of firms and the more pollutant ETS firms, single adoption of innovations does not appear a crucial factor behind the enhancement of productivity.

Tab 2: Results from OLS regressions: specific ICT and EIs covariates

	Whole Sample	ETS Sectors	Non ETS Sectors
		LnVaEmp2010-2011	
Food	0.078		0.090
	(0.065)		(0.072)
Textile	-0.321***		-0.328***
	(0.065)		(0.069)
Shoes	-0.249***		-0.263***
	(0.080)		(0.082)
WoodRubbPlasOther	-0.378***		-0.365***
	(0.054)		(0.053)
PaperPrinting	-0.233**	-0.014	
	(0.115)	(0.113)	
CokeChemical	0.122**	0.255***	
	(0.061)	(0.074)	
NonMetallic	-0.165**	0.028	
	(0.072)	(0.087)	
Metallurgy	-0.202***		
	(0.041)		
20-49 emp.	-0.075	-0.048	-0.073
	(0.050)	(0.099)	(0.059)
50-99 emp.	-0.039	-0.071	-0.012
	(0.045)	(0.084)	(0.053)
100-249 emp.	-0.033	0.024	-0.058
	(0.047)	(0.086)	(0.055)
KStockEmp0608	0.096***	0.137***	0.080***
	(0.022)	(0.048)	(0.022)
CentralReg	0.035	-0.015	0.047
	(0.030)	(0.053)	(0.037)
Prod	-0.045	-0.128*	0.001
	(0.035)	(0.069)	(0.041)
Proc	0.088**	0.176*	0.044
	(0.039)	(0.098)	(0.039)
Export	0.185***	0.220*	0.177**
	(0.061)	(0.120)	(0.073)
Train_d	0.050	0.059	0.039
	(0.034)	(0.075)	(0.042)
ENERGY	-0.175**	-0.048	-0.325***
	(0.076)	(0.112)	(0.102)
CO2	0.169*	0.066	0.296**
	(0.091)	(0.099)	(0.146)
EMISSIONS	-0.060	-0.096	-0.061
	(0.066)	(0.096)	(0.090)
EMASISO	0.063	0.120	0.059
	(0.059)	(0.115)	(0.068)
MRP	-0.033	0.001	-0.046
	(0.032)	(0.059)	(0.038)
ERP	0.032	0.030	0.056
	(0.032)	(0.065)	(0.040)
ICT_BS	-0.018	-0.042	-0.010
	(0.030)	(0.055)	(0.038)
ICT_PROD	-0.034	-0.005	-0.041
	(0.034)	(0.067)	(0.040)
ICT_COOP	-0.041	0.022	-0.067*
	(0.033)	(0.065)	(0.039)
ICT_INFOSERV	0.035	0.059	0.021
	(0.073)	(0.070)	(0.150)
_cons	3.705***	3.277***	3.780***
	(0.131)	(0.253)	(0.156)
N	555	183	372
AdjR2	0.302	0.278	0.316
F(d.f.)	12.432(27)	5.929(22)	10.517(23)
p-value	0.000	0.000	0.000

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

The regressions in Tables 1 and 2 thus show that the EIs and ICT variables, quite unexpectedly, do not extensively affect the labour productivity besides specific and rare cases. Nevertheless, this lack of evidence may still be coherent with the fact that synergic adoption of innovations is needed to reconcile EI with economic performances (the strong version of the Porter hypothesis): more than one innovation is to be adopted. This leads to the key hypothesis of the paper: whether a joint complementary oriented adoption of ICT and EI is behind enhanced productivity performances.

When we enhance our analysis by testing the complementarity among this set of variables, interesting results emerge. Table 3 details the complementary tests conducted on EIs and ICT couples of variables[12]. The complementary test suggests that in the whole sample and among ETS sectors there is only a complementarity between the introduction of any kind of eco innovation and the ICT practices related to buy-and-sell activities. This might suggest that the dematerialization from ICT practices is associated with the introduction of eco innovation once we consider the whole sample and the ETS sector. As suggested in the literature, the application of ICT can permit to enhance the ‘impact’ of EIs activities on firm’s performance. However, the presence of this single result points out that the existence of EIs/ICT complementarities on productivity is not so predictable. The complementarity between these two ‘spheres’ of innovation activities, as for other types of innovations and other types of outputs over which to measure the synergetic, complementary effects (e.g. Schmiedeberg 2008; Polder et al. 2010; Hottenrott et al. 2012), cannot be conceived as a ‘low hanging fruit’ that firms can easily reach through simple strategies. On the contrary, the exploitation of the potential complementarities likely needs the development and deployment of complex innovation strategies that entail techno-organisational changes and human capital empowerment (Antonioli et al. 2013). In addition, the synergies among EIs and ICT can be very specific to ICT practices and EIs adoption. In order to verify the existence of these specificities in complementarity we run our tests on specific EIs/ICT couples as shown in tables 5, 6 and 7.

[12] The set of tests is based on several regressions, each test refers to a single regression as specified in equation (4). For space constraint we do not report the regression outputs, but they are available upon request from the authors.

Tab.4: Complementarity tests for general ICT and environmental innovations. Output variable over which the tests are computed is: LnVAEMP2010-2011

ICT_D/ECOINNO		Whole sample		ETS Sectors		NonETS Sectors	
(Mean value used for dicotomisation)		Wald test§	Sign of the linear combination (b1+b4)+ (-b2-b3)	Wald test§	Sign of the linear combination (b1+b4)+ (-b2-b3)	Wald test§	Sign of the linear combination (b1+b4)+ (-b2-b3)
		(Adj. p-vale for: H_0: coeff. 11+00 >= coeff.10+01)^		(Adj. p-vale for: H_0: coeff. 11+00 >= coeff.10+01)^		(Adj. p-vale for: H_0: coeff. 11+00 >= coeff.10+01)^	
ECOINNO	ICT_INTRO	0.02 (0.44)	≤ 0	1.31 (0.87)	≥ 0	0.18 (0.33)	≤ 0
ECOINNO	MRP	2.25 (0.06)	≤ 0	0.39 (0.26)	≤ 0	1.26 (0.13)	≤ 0
ECOINNO	ERP	0.57 (0.22)	≤ 0	0.18 (0.66)	≥ 0	0.58 (0.22)	≤ 0
ECOINNO	ICT_BS	**3.10*** **(0.96)**	**≥ 0**	**4.07**** **(0.97)**	**≥ 0**	0.29 (0.7)	≥ 0
ECOINNO	ICT_PROD	0.59 (0.22)	≤ 0	0.03 (0.57)	≥ 0	1.21 (0.13)	≤ 0
ECOINNO	ICT_COOP	0.00 (0.52)	≥ 0	0.56 (0.77)	≥ 0	0.63 (0.21)	≤ 0
ECOINNO	ICT_SERV	0.00 (0.49)	≤ 0	0.00 (0.51)	≥ 0	2.08 (0.92)	≥ 0

§ Since we are testing one linear restriction at a time the Chi2 distribution has 1 degree of freedom as the number of the linear restrictions; H0: b1+b4-b2-b3=0; Critical values of F distribution with one degree of freedom in the numerator: 6.63, 3.84 and 2.71 (***1%, ** 5% and * 10% level of significance respectively);
^Adjusted p-value for inequality tests when the Wald F statistics has 1 degree of freedom in the numerator
(b1+b4)+(-b2-b3)≥0 is index of supermodularity
(b1+b4)+(-b2-b3)<0 is index of submodularity

Table 5 presents the results of the EIs/ICT couple-specific complementarity tests for the whole sample of firms. The results suggest that there is a complementarity between energy saving innovations and the ICT used to manage buy-and-sell activities, which supports the hypothesis that ICT and energy saving technologies mutually reinforce their impact on productivity, and that is strategically optimal for firms to jointly introduce these two types of innovations, because of the productivity gains this strategy entails when compared to the adoption of one or the other of the two innovations: ENRGY and ICT_BS. The same reasoning also holds for the couple EMASISO/ICT_SERV: jointly adopting certified green processes of production and ICT used to exchange information and services impacts more on the productivity than adopting one or the other of the two innovations. The implementation of e-commerce practices seems to work in combination with EIs innovation to increase labour productivity given a better organization of economic activities which reinforces the enabling effect that ICT can have in the economy.

Although we have evidence of the two complementarities above, we cannot neglect the substitutability relation that seems to emerge between the following two specific innovations: EIs introduced to reduce emissions and the introduction of Material Requirement Planning (MRP) management system. This management practice permits to improve the process of production by using computer based management and tracking system, which can be considered an enabling effect of ICT adoption. This allows to increase flexibility and efficiency in the production and distribution process. The two specific types of innovations seem to increase productivity more when not adopted in combination, than when jointly implemented. This result may be due, although we do not test for that, to the lack of some needed corollary changes in organization or in human resource management practices. This absence in the production organisation may prevent the firm adopting both the EMISSION and MRP innovations to fully exploit their synergies.

Tab 5: Complementarity tests for specific ICT and environmental innovations. Output variable over which the tests are computed is: LnVAEMP2010-2011

ICT_D/ECOINNO				Whole sample			
(Mean value used for dicotomisation)		Wald test§	Sign of the linear combination (b1+b4)+(-b2-b3)			Wald test§	Sign of the linear combination (b1+b4)+(-b2-b3)
		(Adj. p-vale for: H_0: coeff. 11+00 >= coeff.10+01)^				(Adj. p-vale for: H_0: coeff. 11+00 >= coeff.10+01)^	
ENERGY	ICT_INTRO	0.28 (0.70)	≥ 0	EMISSIONS	ICT_INTRO	0.45 (0.25)	≤ 0
ENERGY	MRP	1.09 (0.14)	≤ 0	EMISSIONS	MRP	**3.37*** **(0.03)**	**≤ 0**
ENERGY	ERP	0.51 (0.23)	≤ 0	EMISSIONS	ERP	2.34 (0.06)	≤ 0
ENERGY	ICT_BS	**3.61*** **(0.97)**	**≥ 0**	EMISSIONS	ICT_BS	0.83 (0.81)	≥ 0
ENERGY	ICT_PROD	0.09 (0.38)	≤ 0	EMISSIONS	ICT_PROD	0.70 (0.20)	≤ 0
ENERGY	ICT_COOP	0.00 (0.49)	≤ 0	EMISSIONS	ICT_COOP	0.09 (0.61)	≥ 0
ENERGY	ICT_SERV	0.06 (0.59)	≥ 0	EMISSIONS	ICT_SERV	0.04 (0.58)	≥ 0
CO2	ICT_INTRO	0.06 (0.59)	≥ 0	EMASISO	ICT_INTRO	0.00 (0.49)	≤ 0
CO2	MRP	0.19 (0.32)	≤ 0	EMASISO	MRP	2.13 (0.07)	≤ 0
CO2	ERP	0.02 (0.44)	≤ 0	EMASISO	ERP	0.28 (0.29)	≤ 0
CO2	ICT_BS	0.17 (0.65)	≥ 0	EMASISO	ICT_BS	2.51 (0.94)	≥ 0
CO2	ICT_PROD	0.23 (0.31)	≤ 0	EMASISO	ICT_PROD	0.10 (0.37)	≤ 0
CO2	ICT_COOP	0.16 (0.34)	≤ 0	EMASISO	ICT_COOP	0.01 (0.53)	≤ 0
CO2	ICT_SERV	2.55 (0.94)	≥ 0	EMASISO	ICT_SERV	**2.85*** **0.95**	**≥ 0**

§ Since we are testing one linear restriction at a time the Chi2 distribution has 1 degree of freedom as the number of the linear restrictions; H0: b1+b4-b2-b3=0; Critical values of F distribution with one degree of freedom in the numerator: 6.63, 3.84 and 2.71 (***1%, ** 5% and * 10% level of significance respectively);
^ Adjusted p-value for inequality tests when the Wald F statistics has 1 degree of freedom in the numerator
(b1+b4)+(-b2-b3)≥0 is index of supermodularity
(b1+b4)+(-b2-b3)<0 is index of submodularity

Table 6 and 7 presents the complementarity test on the sub-sample of firms belonging to respectively ETS sectors and non EST sectors

The complementary tests on the ETS sample presented in Table 6 show that the combination of ICT_BS with different type of environmental innovations, namely Emission reduction, Energy saving practices and non-technological standard such as EMAS leads to productivity gains. This result is interesting as it shows that firms which operate in regulated sectors are able to exploit the potential productivity effects of the joint adoption of specific ICT and EI. In fact, it emerges also that there is a complementarity between the adoption of non-technological standards (EMAS and ISO certifications) and both ICT_INTRO and ICT_SERV. The digitalization of services combined with the adoption of green non-technological standards exert a complementary influence on productivity, even in a period of ongoing economic slowdown. Within the ETS sectors the environmental innovation seems to go hand in hand with the enabling effect of ICT adoption and usage.

The complementary nature of specific EIs and ICT shown by our results consistently relates with a previous literature that underlines the positive effect associated with de-materilisation of different economic activities in greening the firms production process. In addition, our evidence for ETS sectors, especially that showing complementarities among different information technologies and organizational changes adopted to meet green EMAS and ISO requirements, is also consistent with several empirical works (e.g. Black and Lynch 2001; Brynjolfsson et al. 2006) that point out how investments in information technologies enables organizational changes, which in turn increase output and productivity (Antonioli et al. 2010).

Tab 6: Complementarity tests for specific ICT and environmental innovations. Output variable over which the tests are computed is: LnVAEMP2010-2011

ICT_D/ECOINNO		ETS Sectors					
(Mean value used for dicotomisation)		Wald test§	Sign of the linear combination (b1+b4)+(-b2-b3)			Wald test§	Sign of the linear combination (b1+b4)+(-b2-b3)
		(Adj. p-vale for: H_0: coeff. 11+00 >= coeff.10+01)^				(Adj. p-vale for: H_0: coeff. 11+00 >= coeff.10+01)^	
ENERGY	ICT_INTRO	1.41 (0.88)	≥ 0	EMISSIONS	ICT_INTRO	0.03 (0.56)	≥ 0
ENERGY	MRP	0.25 (0.30)	≤ 0	EMISSIONS	MRP	0.62 (0.21)	≥ 0
ENERGY	ERP	0.24 (0.68)	≥ 0	EMISSIONS	ERP	1.00 (0.15)	≤ 0
ENERGY	ICT_BS	**4.01** (0.97)**	**≥ 0**	EMISSIONS	ICT_BS	**2.90* (0.95)**	**≥ 0**
ENERGY	ICT_PROD	0.79 (0.81)	≥ 0	EMISSIONS	ICT_PROD	0.52 (0.76)	≥ 0
ENERGY	ICT_COOP	1.41 (0.88)	≥ 0	EMISSIONS	ICT_COOP	2.39 (0.93)	≥ 0
ENERGY	ICT_SERV	0.19 (0.66)	≥ 0	EMISSIONS	ICT_SERV	0.04 (0.58)	≥ 0
CO2	ICT_INTRO	0.31 (0.70)	≥ 0	EMASISO	ICT_INTRO	**8.85*** (0.99)**	**≥ 0**
CO2	MRP	0.16 (0.65)	≥ 0	EMASISO	MRP	0.63 (0.78)	≥ 0
CO2	ERP	0.01 (0.52)	≥ 0	EMASISO	ERP	1.84 (0.91)	≥ 0
CO2	ICT_BS	1.46 (0.88)	≥ 0	EMASISO	ICT_BS	**3.05* (0.95)**	**≥ 0**
CO2	ICT_PROD	0.25 (0.69)	≥ 0	EMASISO	ICT_PROD	2.23 (0.93)	≥ 0
CO2	ICT_COOP	0.01 (0.54)	≥ 0	EMASISO	ICT_COOP	0.79 (0.81)	≥ 0
CO2	ICT_SERV	0.59 (0.77)	≥ 0	EMASISO	ICT_SERV	**3.69* 0.97**	**≥ 0**

§ Since we are testing one linear restriction at a time the Chi2 distribution has 1 degree of freedom as the number of the linear restrictions; H0: b1+b4-b2-b3=0; Critical values of F distribution with one degree of freedom in the numerator: 6.63, 3.84 and 2.71 (***1%, ** 5% and * 10% level of significance respectively);
^ Adjusted p-value for inequality tests when the Wald F statistics has 1 degree of freedom in the numerator
(b1+b4)+(-b2-b3)≥0 is index of supermodularity
(b1+b4)+(-b2-b3)<0 is index of submodularity

The reasoning concerning the results for ETS sectors cannot be translated to the firms belonging to sectors less strictly regulated (NonETS), because, as Table 7 shows, the results are largely in favour of substitutability between EIs and ICT. It might be the case that the timing in EIs and ICT adoption matters. For the NonETS firms the adoption of disjoint ICT and EIs is still more fruitful than it is their combination in the production process. Although we cannot control for the year of ICT and EIs adoption we may argue that firms not subject to stringent environmental regulation are late EIs adopters with respect to ETS firms: at the end of the period 2006-2008, we can speculate. This late adoption, just before the economic recession of 2009, may have displaced these firms more than ETS firms, many of them could have adopted EIs at the beginning of the 2006-2008 period, thus having enough time before the recession to optimally learn how to integrate green processes and technology with other innovations, especially ICT, and gaining productivity advantages soon after the 2009 recession. Although this interpretation is matter of speculation activity, a fact remains: the NonETS firms are less able than their ETS counterpart to exploit synergies among information technologies and environmental innovations. In addition, this happens despite the fact that among the NonETS sectors we count the machinery sector, one of the most technologically advanced sectors in Emilia-Romagna region and the backbone of the regional industrial system.

Tab.7: Complementarity tests for specific ICT and environmental innovations. Output variable over which the tests are computed is: LnVAEMP2010-2011

ICT_D/ECOINNO		NonETS Sectors					
(Mean value used for dicotomisation)		Wald test§	Sign of the linear combination (b1+b4)+(-b2-b3)			Wald test§	Sign of the linear combination (b1+b4)+(-b2-b3)
		(Adj. p-vale for: H_0: coeff. 11+00 >= coeff.10+01)^				(Adj. p-vale for: H_0: coeff. 11+00 >= coeff.10+01)^	
ENERGY	ICT_INTRO	0.88 (0.85)	≥ 0	EMISSIONS	ICT_INTRO	0.32 (0.28)	≤ 0
ENERGY	MRP	0.29 (0.29)	≤ 0	EMISSIONS	MRP	2.19 (0.06)	≤ 0
ENERGY	ERP	0.23 (0.31)	≤ 0	EMISSIONS	ERP	0.78 (0.18)	≤ 0
ENERGY	ICT_BS	0.80 (0.81)	≥ 0	EMISSIONS	ICT_BS	0.01 (0.45)	≤ 0
ENERGY	ICT_PROD	1.58 (0.10)	≤ 0	EMISSIONS	ICT_PROD	**5.33** (0.01)**	**≤ 0**
ENERGY	ICT_COOP	1.14 (0.14)	≤ 0	EMISSIONS	ICT_COOP	1.24 (0.13)	≤ 0
ENERGY	ICT_SERV	1.30 (0.87)	≥ 0	EMISSIONS	ICT_SERV	n.f.	
CO2	ICT_INTRO	0.13 (0.63)	≥ 0	EMASISO	ICT_INTRO	0.44 (0.25)	≤ 0
CO2	MRP	0.22 (0.31)	≤ 0	EMASISO	MRP	2.99* (0.04)	≤ 0
CO2	ERP	0.07 (0.60)	≥ 0	EMASISO	ERP	0.66 (0.20)	≤ 0
CO2	ICT_BS	0.15 (0.35)	≤ 0	EMASISO	ICT_BS	0.56 (0.77)	≥ 0
CO2	ICT_PROD	**3.53* (0.03)**	**≤ 0**	EMASISO	ICT_PROD	**4.43** (0.01)**	**≤ 0**
CO2	ICT_COOP	0.93 (0.16)	≤ 0	EMASISO	ICT_COOP	0.47 (0.24)	≤ 0
CO2	ICT_SERV	**2.92* (0.95)**	**≥ 0**	EMASISO	ICT_SERV	n.f.	

§ Since we are testing one linear restriction at a time the Chi2 distribution has 1 degree of freedom as the number of the linear restrictions; H0: b1+b4-b2-b3=0; Critical values of F distribution with one degree of freedom in the numerator: 6.63, 3.84 and 2.71 (***1%, ** 5% and * 10% level of significance respectively);
^ Adjusted p-value for inequality tests when the Wald F statistics has 1 degree of freedom in the numerator
(b1+b4)+(-b2-b3)≥0 is index of supermodularity
(b1+b4)+(-b2-b3)<0 is index of submodularity
n.f. means that the test computation is not feasible because one of the state of the world lack of any firm.

6. Conclusions

This article has aimed at studying to what extent the joint adoption of environmental innovation and ICTs affect the labour productivity of firms.

Our econometric evidence points out the existence of both complementarity and substitutability among EIs and ICT on labour productivity.

More in detail, once we consider the whole sample of firms, the results show that there is a complementarity between energy saving innovations and the ICT used to manage buy-and-sell activities, which supports the hypothesis that EIs can have an impact in productivity growth once they are jointly introduced with ICT, really supporting the enabling effect. For the whole manufacturing regional system the results stemming from our representative sample seem to weakly support the ideas that competitive advantages may be gained through the joint adoption of EIs and ICT, partially supporting the 'strong' version of the Porter hypothesis (Porter and van der Linde, 1995; Porter 2010).

However, detailing the analysis at subsample levels, distinguishing most polluting and regulated sectors (ETS) from the less polluting and regulated ones (NonETS), the results considerably change.

On the one hand, our evidence shows that a complementarity between the adoption of certain type of ICT applications such as e-commerce and digitalisation of the economic activities and specific types of EIs does exist, especially for organisational changes adopted to meet green-certificates requirements (e.g. EMAS, ISO14001). This result corroborates, also for green investments and innovation, what an empirical literature has shown in terms of ICT and organisational changes complementarity on productivity (Black and Lynch, 2001; Brynjolfsson et al. 2006). Such an evidence, however, holds only for a certain type of firms: those belonging to the most polluting sectors and subject to ETS regulation. It seems quite clear we are in front of the 'strong' version of the Porter hypothesis at work: policy stringency push the firms to invest in green technologies and organisational changes, but are only the most technologically advanced firms, especially in terms of ICT, which facilitate the EIs adoption as well, to benefit from gains in productivity.

On the other hand, for the less regulated firms substitutability relations mainly emerge between EI and ICT couples of innovation, that is to say, larger gains in productivity are reached through the adoption of EIs or ICT, but not by the deployment of their combinations. In the

NonETS sectors the EIs strategies seem to not be fully embedded with the ICT strategies, lowering down the potential 'impact' on labour productivity.

The results confirm the assumption that complementarities are sector specific and innovation specific. They do not hold in every manufacturing sector and they do not hold for any mix of EIs and ICT adoption. The beneficial mix of innovation adoptions for the firms, in terms of increased labour productivity, must be carefully chosen and implemented.

Our study has some limitations which provide suggestions for future research. We have no detailed information about the reasons that motivated the adoption of ICT and environmental innovation, however, the complementarity test shows that the joint adoption affects the labor productivity of firms. The time span after the EIs and ICT adoption could be too short to provide robust evidence on productivity 'effects', especially in a period of enduring economic slowdown.

Appendix

Tab.A1 - Distribution by sector and size of population and sample firms

Population								
Sectors	Freq.	Percent	***Size***	Freq.	Percent	*Provincia^*	Freq.	Percent
CokeChemical	130	3.2	20-49	2720	66,86	Out region	91	2.24
Food	382	9.39	50-99	726	17,85	BO	904	22.22
Machinery	1,387	34.1	100-249	414	10,18	FC	346	8.51
Metallurgy	883	21.71	250+	208	5,11	FE	196	4.82
NonMetallic	285	7.01				MO	891	21.9
PaperPrinting	197	4.84				PC	200	4.92
Shoes	236	5.8				PR	381	9.37
Textile	119	2.93				RA	229	5.63
WoodRubberPlasticOther	449	11.04				RE	667	16.4
						RN	163	4.01
Total	4,068	100		4,068	100		4,068	100
Sample								
Sectors	Freq.	Percent	***Size***	Freq.	Percent	*Provincia^*	Freq.	Percent
CokeChemical	28	5.05	20-49	208	37,48	Out region	20	3.6
Food	49	8.83	50-99	193	34,77	BO	115	20.72
Machinery	232	41.8	100-249	96	17,30	FC	40	7.21
Metallurgy	94	16.94	250+	58	10,45	FE	30	5.41
NonMetallic	42	7.57				MO	124	22.34
PaperPrinting	19	3.42				PC	25	4.5
Shoes	12	2.16				PR	49	8.83
Textile	23	4.14				RA	32	5.77
WoodRubberPlasticOther	56	10.09				RE	96	17.3
						RN	24	4.32
Total	555	100		555	100		555	100

^*Provincia* is a statistical geographical unit coded as NUTS3 level by EUROSTAT

Tab. A2 – Construction of the variables used in the analysis

Economic Performance	
LnVAEMP2010-2011	Log of the average value added per capita on the period 2010-2011
Environmental Innovations	
Environmental innovation (**ECOINNO**)	Dummy variable: 1 if the firm introduced an environmental innovation; 0 otherwise
Energy/Material reduction per unit of product (**ENERGY**)	Dummy variable: 1 if innovations addressed to reduce use of materials and/or energy by output unit (included recycling) have been adopted; 0 otherwise
CO_2 reduction (**CO_2**)	Dummy variable: 1 if innovations addressed to reduce CO_2 emissions have been adopted; 0 otherwise
Emissions reduction for soil, water and air (**EMISSIONS**)	Dummy variable: 1 if innovations addressed to reduce emissions for soil, water and air have been adopted; 0 otherwise
Adoption of procedures like EMAS and ISO14001 (**EMASISO**)	Dummy variable: 1 if procedures that structurally identify environmental performance have been adopted; 0 otherwise
ICT	
ICTNTRO	Dummy variable: 1 if the number of ICT management systems implemented is above the sample average; 0 otherwise.
MRP	Dummy variable: 1 if the ICT management system Material Requirements Planning (MRP) has been introduced; 0 otherwise
ERP	Dummy variable: 1 if the ICT management system Enterprise Resource Planning (ERP) has been introduced; 0 otherwise
ICT_BS	Dummy variable: 1 if the ICT systems implemented are addressed to manage buying and selling activities; 0 otherwise
ICT_PROD	Dummy variable: 1 if the ICT systems implemented are addressed to manage the production process; 0 otherwise.
ICT_COOP	Dummy variable: 1 if the ICT systems implemented are addressed to manage cooperation with clients and suppliers (e.g. post selling services); 0 otherwise.
ICT_SERV	Dummy variable: 1 if the ICT systems implemented are addressed to manage the exchange of information and services; 0 otherwise.
INNOVATIONS	
Prod	1 in firm introduced process innovation; 0 otherwise
Proc	1 in firm introduced product innovation; 0 otherwise
TRAIN_D	1 if firm adopted training programs of any kind; 0 otherwise

Controls	
Size dummies	4 size dummies according o the number of employees: 20-49 employees; 50-99 emp.; 100-249 emp.; more than 249 emp)
Sector dummies….	9 secotrs dummies according to a two digit Nace Rev2 classification. Sectors are grouped according to the Italian RAMEAdata. The whole set of sector dummies is decomposed in two subsets of ETS and NonETS sectors:……..
…ETS	PaperPrinting, CokeChemical, NonMetallicMineralProducts, Metallurgy
…NonETS	Food, Textile, Shoes, WoodRubberPlasticOther, Machinery
CentralReg	Dummy variable: 1 if the firm belongs to one of the provinces constituting the backbone of the Emilia-Romagna industrial system (Bologna, Parma, Modena, Reggio-Emilia); 0 otherwise
Export	Percentage of turnover made on international markets
KStockEmp0608	Average capital stock per capita on the period 2006-2008

Tab.A3 - Descriptive statistics

	Whole sample (555 firms)				ETS firms (183 firms)				Non ETS firms (372 firms)			
	Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max
Economic Performance												
LnVAEMP2010-2011	4.01	0.39	2.13	5.40	3.97	0.39	2.13	4.87	4.03	0.38	2.35	5.40
Environmental Innovations												
ECOINNO	0.20	0.40	0	1	0.27	0.45	0	1	0.16	0.37	0	1
ENERGY	0.15	0.36	0	1	0.22	0.42	0	1	0.11	0.31	0	1
CO2	0.12	0.32	0	1	0.16	0.37	0	1	0.09	0.29	0	1
EMISSIONS	0.14	0.35	0	1	0.19	0.39	0	1	0.12	0.32	0	1
EMASISO	0.14	0.35	0	1	0.18	0.39	0	1	0.13	0.33	0	1
ICT												
ICTNTRO	0.44	0.50	0	1	0.30	0.46	0	1	0.51	0.50	0	1
MRP	0.36	0.48	0	1	0.22	0.42	0	1	0.42	0.49	0	1
ERP	0.48	0.50	0	1	0.37	0.48	0	1	0.53	0.50	0	1
ICT_BS	0.42	0.49	0	1	0.42	0.49	0	1	0.43	0.50	0	1
ICT_PROD	0.66	0.47	0	1	0.63	0.48	0	1	0.67	0.47	0	1
ICT_COOP	0.64	0.48	0	1	0.60	0.49	0	1	0.66	0.48	0	1
ICT_SERV	0.93	0.26	0	1	0.87	0.33	0	1	0.95	0.21	0	1
INNOVATIONS												
Prod	0.70	0.46	0	1	0.62	0.49	0	1	0.73	0.44	0	1
Proc	0.68	0.47	0	1	0.69	0.46	0	1	0.68	0.47	0	1
TRAIN_D	0.80	0.40	0	1	0.85	0.36	0	1	0.78	0.41	0	1
Controls												
Size dummies	\	\	0	1	\	\	0	1	\	\	0	1
Sector dummies	\	\	0	1	\	\	0	1	\	\	0	1
CentralReg	0.69	0.46	0	1	0.70	0.46	0	1	0.69	0.46	0	1
Export	0.33	0.31	0	1	0.26	0.27	0	1	0.37	0.32	0	1
KStockEmp0608	3.37	0.94	-0.99	6.11	3.60	0.86	0.04	5.66	3.26	0.95	-0.99	6.11

Appendix B

Selected questions for ICT and EI variables construction. The answers refer to the period 2006-2008.

ENVIRONMENTAL INNOVATION (EI)

Q1: Did the firms adopt "environmental" products and/or process technological innovations that induced the following 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

CO2=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

Q2: Has the firm 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

ICT

Q3. Which types of management systems and network integration did you adopt?

	Yes/No
1. Management information system	
2. Electronic Data Interchange (**EDI)**	
3. Material Requirements Planning (**MRP)**	
4. Supply Chain Management (**SCM)**	
5. Customer Relationship Management (**CRM)**	
6. Enterprise Resource Planning (**ERP)**	

ICT_INTRO=(number of the items in Q3 with a positive answer)/(number of all the items in Q3); dichotomised for complementarity test as 1 if the index is above the average and 0 otherwise

MRP =1 if the firm introduced MRP systems: 0 otherwise

ERP =1 if the firm introduced ERP systems; 0 otherwise

Q4. Which types of activities are supported by ICT?

	Yes/No
1. Acquire information and services	
2. Provide information and services	
3. Manage buy-and-sell orders online	
4. Manage the production process and control quality and time	
5. Cooperate with clients and suppliers (post-selling services)	

ICT_BS=1 if the item 3 in Q4 has a positive answer; 0 otherwise

ICT_PROD=1 if the item 4 in Q4 has a positive answer; 0 otherwise

ICT_COOP=1 if the item 5 in Q4 has a positive answer; 0 otherwise

ICT_SERV=1 if the item 1 or 2 in Q4 have a positive answer; 0 otherwise

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