Università degli Studi di Ferrara

DOTTORATO DI RICERCA IN

ECONOMIA

CICLO XXVII

COORDINATORE Prof. Massimiliano Mazzanti

Linking emissions, innovation and competitiveness. The European path towards sustainability

Settore Scientifico Disciplinare SECS-P/01

Dottorando

Dott. Marianna Gilli

____

Tutore

Prof Lucio Poma

____

Cotutore

Prof Massimiliano Mazzanti

____

Anni 2012/2014

Table of contents

List of Tables

Chapter 1

Chapter 2

Chapter 3

List of Figures

Introduction

At the end of the '90s, 186 countries were signing the international agreement known as Kyoto protocol, which commited its participants to the achievement of a binding emission target throughout its different phases. Within this international framework Europe played its role by setting up a multitude of policy programmes to support innovation, investment and the development of the right infrastructure towards a low-carbon economy together with the defense of the economic growth.

As it is commonly acknowledged in the literature (Popp et al. 2009a; Jaffe et al. 2002; Porter & Linde 1995) environmental policy can help firms to reduce polluting emissions by helping them to identify weaknesses and wastefulness in their production processes, incentivizing the adoption of new practices and simultaneously reducing their environmental impacts. Along with other factors, policy turned to be pivotal in the adoption of environmental innovation (Ambec et al. 2013; Carson 2009), which have been defined as a particular kind of innovation which can significantly lower pollution, environmental risk and other negative impacts of resources use (Kemp & Pearson 2007)

However, even if both the drivers and the effects of innovation and environmental innovation can be considered of relevance to address the policy decision-making process, the literature mostly focused on the factors which incentivize the adoption of innovation. Therefore, researches in the field of the environmental effects of innovation are still rather scarce.

The aim of this dissertation is thus to contribute to this emerging stream of research.

The analysis of the existing contribution, highlighted the presence of at least three mechanism through which innovation spreads its effect on the environment.

A first mechanism through which green technological change can affect environmental but also economic performances, is by inflating the effect of other key variables; for example in a paper by Mazzanti & Zoboli (2009), which analyses data for 29 manufacturing sectors in Italy and 6 pollutants between 1991-2001, innovation effects are not observed directly but are entangled into an increased labour productivity (i.e., labour productivity increases due to the introduction of new products or processes). In Marin & Mazzanti (2010), which analyses the relation between environment and labour productivity in Italy between 1990 and 2007, innovation efforts are disentangled from environmental productivity including data on R&D; results show that innovation efforts are weakly economically relevant, indicating that these efforts alone cannot yet be considered as a driver of an improved environmental performance.

A second relation between innovation and environmental performance is driven by administrative and geographical features: local government and regulation as well as local industrial specialization and innovative capabilities, act by influencing decisions of firms in neighbouring territories. Mazzanti & Montini (2010), analyses environmental performance of a set of ten pollutants in Rome and in the Lazio region with respect to the average Italian performance. Regional environmental performance resulted to be better than the national one, especially due to structural and present economic conditions which makes Lazio a less emission intensive and energy intensive region; however, other factors have been found significant in abating emission: first the role of both private and public expenditure in R&D and particularly their interaction; second and most important , innovation appears to be predominant to assume an higher importance than policies targeted on environmental externalities in reducing emissions. Costantini et al. (2013), consider the role of sectorial innovation, regional environmental spillovers and environmental policies to investigate the determinants of sectorial environmental performance in Italy. Results show that innovation spillovers and environmental spillovers can drive regional and sector-specific environmental outcomes; according to the authors, this may indicate the presence of both a sectorial agglomeration in restricted areas and the presence of a common innovation pattern within regions (i.e., common choices in the adoption of cleaner or dirtier technologies, within geographical areas). Finally, they argue that spillovers may also play a greater role than innovation itself in defining environmental performances.

The third and final channel through which innovation affects environmental sustainability is industrial spillovers. As underlined by Dopfer (2012) it is at the “meso” level, which indicates a sectorial level of analysis, that innovation diffuses. Therefore, industrial spillovers may allow a wider adoption of innovation and consequently may contribute to enhance some potential environmental benefit. Corradini et al. (2014), who investigates the link between environmental protection and innovation, analyses 23 manufacturing branches in the EU15 from 1995 to 2006, and find a positive relation between investment decision in innovation by one sector and pollution abatement efforts of other sectors (for examples, investment in R&D in a sector, positively reacts to pollution abatement choices in other sectors). Moreover, the authors underline how also in this case, environmental spillovers appear to be more important than knowledge spillovers in determining environmental performances.

Beside these contributions, there exist other analysis which highlighted some environmental effect of innovation, even though their main focus is not on the investigation of this relation. For example, Ghisetti & Quatraro (2013), examined endogenous factors inducing intra-sectorial diffusion of innovation and found the introduction of green technologies as a response to environmental performance; in other words, polluting firms often commit resources to environmental-friendly technologies as a response to an increased awareness of their social and environmental responsibility as well as a precautionary action towards future regulation. Wang et al. (2012) analyses the impact of both fossil fueled technologies and carbon free technologies on CO2 emissions across 30 Chinese provinces between 1997 and 2008; the authors find that while fossil fueled technologies do not appear to affect CO2 levels, carbon free technologies have a significant influence on pollution abatement, particularly in western China. Carrión-Flores & Innes (2010), studies the bi-directional link between environmental innovation and air pollution for 127 American manufacturing industries over the period 1989-2004. Their findings show a negative and significant bi-directional relation, namely innovation reduces the cost of meeting pollution targets while tightened pollution targets elevate the potential cost-saving benefits of environmental R&D, enhancing more innovation.

Given the scarcity of contribution in this field and consequently, the lack of a framework of reference, there are rooms to extend and deepen the analysis. First, the majority of the articles collected focused on the Italian context which certainly represents a heterogeneous economic and environmental context. However, similar studies carried across the European Union would be of greater interest, in the light of the strongly different economic and institutional conditions among its countries, as well as its very heterogeneous environmental responsibility awareness. Moreover, also papers which consider extra-European countries are not numerous. A possible reason behind the lack of European and worldwide analysis in this sense might be a scarcity of adequate and relevant data. Second, the majority of the articles presented in this section uses an indicator of environmental productivity (Repetto 1990), which beside being informative from an economic point of view, may not be adequate alone to evaluate the effects of innovation or policies, for four main reason: first, both policies and innovation are targeted to affect a physical level of emission; second, variation of the environmental productivity indicator may be due to change in value added rather than changes in emission; third, econometric analysis can lead to biased estimates and inflated levels of significance because regressors might be more correlated with value added than with emissions; fourth, endogeneity issues may arise due to the presence of value added[1]. Therefore, there is the need to consider also effects of innovation and other relevant variables on the physical level of emissions other than on the environmental productivity indicator. Finally, papers in this stream of research often consider only the sectorial level of analysis. Even if this is certainly the most appropriate dimension for this studies because of its importance in the diffusion of innovation, from one side efforts should also be directed towards firm level analysis to better understand microeconomics dynamics behind the achievement of a better environmental outcome; from the other side, also analysis at country level would be informative of the macroeconomic dynamics which drive the aggregated environmental performances.

The purpose of this thesis is to provide new insight on the effect of innovation along with other factors, on environmental performance. Economic, innovative and environmental performances of various European countries are considered, to the extent to enrich the literature by providing a European perspective; the unit of analysis is the sectorial level. Moreover, to enrich the analysis CO2 emissions level is included beside indicator of emission intensity and environmental productivity.

Environmental performances, innovation and competitiveness are then broken down in three different aspects. Chapter 1 provides a descriptive analysis of the economic innovative and environmental performances of five main European countries, representing very diverse economic and institutional contexts[2]. Following a rich strand of literature (for example: Mohnen & Röller 2005; Antonioli et al. 2013; Cainelli & Mazzanti 2013) Chapter 2, analyses the interactions between different categories of innovation practices and their effect on environmental productivity. Finally, Chapter 3 analyses the dynamic relation between innovation and CO2 performances using a panel of 14 branches of the manufacturing sector in 13 European countries through fifteen years. Finally, a general conclusive section will collect and summarize the most important remarks.

.

[1] The same reasoning applies to the emission intendity indicator, computed as $^{Emissions}/_{Value\ Added}$

[2] Namely: Swden, Finland, France, Germany and Italy.

1. Environmental Innovation Adoption and Economic – Environmental Performances. Sector Perspective on the EU: Structural Change and Dynamic Issue

1.1. Introduction

The main aim of the work is to draw a picture of the EU countries performances at the sector level in terms of eco-innovation (EI), economic specialization, economic productivity and environmental efficiency (Kemp 2000). The question is in a nutshell whether the EU economy has moved towards sectors that lead the way in terms of EI, and primarily whether there is a correlation between innovation (adoption), economic and environmental performances at a meso level of the analysis (sectors).

The rich information stemming from the CIS (Community Innovation Survey) 2008 is exploited. It covers all innovation adoptions by EU firms over 2006-2008, and for the first time includes EI along various types: CO_2 reduction, energy efficiency, material and waste reduction, emission reductions, EMS/ISO adoptions among others.

The development and application of EI is the key issue around which the all reasoning on the green economy may revolve, and it is becoming the conceptual reference point for many regional and international public policies and management strategies. One of the most recent definitions of eco-innovation defines it as the production, application or use of a product, service, production process or management system new to the firm adopting or developing it, and which implies a reduction in environmental impact and resource use (including energy) throughout its life-cycle. This definition includes innovations whose environmental effects are not intentional. A relevant distinction can be made between end-of-pipe technologies and clean technologies integrated in the production process (for more insights around this definition see Kemp & Pontoglio 2011).

The wide dataset and array of information on EI allows describing in depth EI and its links with major factors that characterize the EU competitiveness and innovation potential. The aim is to integrate the EUROSTAT sector based CIS2008 data for EI with data on environmental performance by sector on waste and emissions and economic productivity, namely labour productivity as main indicator of economic performance

(WIOD[3] sources), thus a meso economics perspective is taken, in line with the evolutionary thinking on innovation. Micro and meso levels are key to the understanding of innovation and economic-environmental performances (Dopfer 2012). The meso level is conceptually robust to analyse the diffusion of innovation and furthermore allows an easier comparison across sectors and countries, similar to that characterizing patent based analyses.

The empirical analysis is aimed at comparatively shedding light on the performances of EU sectors over the last decade. I first compare EI performances for key EU countries (Germany, Italy, France, and Netherlands, Sweden) that represent diverse economic and institutional settings. Leader and laggards are drawn out for the overall economy. It is of interest to associate EI diffusion performances with economic and environmental trends that characterize the EU economy in the way to possible changing specializations (within services and industry). Consequently, the focus is on analysing main sectors in terms of value added, and the most dynamic sectors, namely those that have greatly increased and diminished their value share over the recent past. One can thus have a look at both a static and a dynamic picture of the EU economic system.

The integrated analysis aims at shedding light mainly on:

- Whether and how 'EI adoption intensity' (by sector, by country) matches country environmental performances.
- Whether and how 'EI adoption intensity' matches country (changing) specialization, namely as example whether a country is specialized (ing) in sectors which shows high/low intensity of EI.

The analysis takes into account industry and services on the view of the structural/composition changes that are occurring in the EU economy. Finally, a decomposition of countries environmental performance differentials through the use of a shift-share analysis is proposed. This final exercise seeks to investigate if infra-countries environmental differentials are more related to different market structures (for instance specialisations in greener sectors) or depend on sectorial emission efficiency. In addition to extend the picture to all EU countries, chapter 2 tests whether EI and other typologies of 'normal' innovations are integrated or not, namely whether they are jointly adopted / positively correlated in major EU sectors. Finally, the productivity and employment effects of EI and joint innovations can be ascertained by more refined quantitative models. Here, a robust preliminary overview that sketches main factors and may offers food for thought to policy makers and innovation practitioners is offered. The last two sections propose two

[3] See Timmer (2012)

additional exercises aimed at providing a clearer picture of intra country differential in both sectorial environmental and innovative performances.
In the following, Section 2 develops the conceptual background, Section 3 presents the results of the main analysis, Section 4 reports evidence for the shift-share decomposition exercise and Section 5 concludes.

1.2. Conceptual Background

The generation of new Input Output (I-O) tables at European Union (EU) level in recent EU FP7 projects, such as EXIOPOL and WIOD, is a good development towards more effective production and analysis of hybrid economic-environmental accounts, as well as the excellent releases by EUROSTAT of a first National Accounting Matrix including Environmental Accounts (NAMEA) for EU in 2011 (Costantini et al. 2011). Efforts in economic-environmental accounting offer rich extensions and potential links to many fields, such as innovation studies, but also mounting studies on international trade effects on the environment according to both consumption and production sustainability.
The dynamic framework is intrinsically related to ongoing transformations of the economic and environmental systems, with innovation and policy as main levers of changes. Analysis of such a constantly transformed environment is what makes broad and hybrid approaches different from static, very narrow fields. The real challenge today is a deeper analysis and broader understanding of the dynamic world that presents many methodological, theoretical and empirical challenges. After consolidation of static environmental economics theory, dynamic thinking has increasingly emerged since the mid ‘90s.

A few more words on sector analyses and innovation should be added. Specific sector performances (innovative, environmental, and economic) are crucial to the future competitiveness and achievement of environmental targets in the EU.
Then, given the relevance of sector interdependences, the manufacturing sector cannot be the only focus of analysis when looking at innovation effects in open innovation systems. The increasing role of vertical integration makes it necessary to look at both industry and service industry innovation dynamics. The increasing role of vertical integration makes necessary to look at both within industry and industry-service innovation dynamics, especially for the case of ‘producer services’, in the standard OECD classification (sectors

from 50 to 74 in ISIC, especially financial, communication and business services, which also highlight the role of ICT in relation to environmental performances).

Moreover, the effects of environmental policy on the innovation system should take into account the increasing share of imported intermediate inputs implies that emissions associated to domestic output are partly leaked abroad through trade. By itself this can improve sectorial direct resource efficiency (RE) indicators. The ‘technology effect’ in this trade related perspective is important since it makes necessary to study both sides of the coin: how emissions are relocated abroad, but also how trade drives technology shifts/spillovers and how green technology can enhance the competitiveness of the EU.

A multi-sector country based specific perspective is thus needed to discover weakness and strengths under the overall macroeconomic performance and strengthen future innovation trajectories in the EU. A meso/micro level perspective goes directly into the centre of innovation generation, diffusion, including the relevant technological spillovers occurring within industry, between services and industry, between innovators and adopters located in different sectors/countries. The heterogeneity of national policies, associated with the economic and technological interdependencies occurring between actors in various countries, also emphasizes the possibility of other ways of inter country policy transmissions.

1.3. Environmental innovation adoption, economic and environmental performance

I use available data at sectorial level from both European Community Innovation Survey and WIOD database, to compare the economic and eco-innovative performance of five main European countries, namely Italy, Germany, France, Netherlands and Sweden. Five major countries are considered, that at the same represent different economic-institutional features to offer food for thought for further analyses.

WIOD database allows using data on value added, employment and CO2 and SOx emission; CIS data concern here three environmental innovation indicators out of the complete set: increasing energy efficiency, emissions reduction and waste reduction.

The World Input Output Database (WIOD) is a result from a European Commission funded project as part of the seventh Framework Programme and has been developed to analyse the effects of globalization on socio-economic variables and trade, in a wide range of countries (the 27 EU Member States and other 13 major counties in the world, from 1995 to 2009). WIOD is made up of four different accounts (World Tables, National

Tables, Socio Economic Accounts and Environmental Accounts) For the purpose of this work, Socio-Economic and Environmental Accounts are used, both providing a wide range of economic variables such as value added and environmental variables as CO2 and Sox emission[4].

Community Innovation Survey (CIS) are a series of surveys produced by the national statistical offices of the 27 European Union member states, also covering the European Free Trade Association countries and the EU candidate countries. The surveys have been implemented since 1993, on a two-yearly basis and are designed to obtain information on innovation activities of enterprises, including various aspects of innovation process, as innovation effects, cost and sources of information used. Data are collected at micro level, using a standardized questionnaire developed in cooperation with the EU Member States to ensure the comparability across countries.

The sixth CIS (2006-2008) collects data on environmental innovation for the first time[5]. Though it is a cross section dataset, it captures a 3 years time span of EI and is the first CIS survey that has included EI at EU level ever. Community Innovation statistics based data are the main data source for measuring innovation in Europe and are used in academic research as in Horbach et al. 2012, Borghesi et al. (2012) and Veugelers (2012) which exploit data for Germany, Italy, Belgium respectively. Micro and meso aggregation are available.

From a conceptual point of view, I refer to the integrated concepts of sectorial and national systems of innovation which have consolidated in the innovation oriented evolutionary theory (Malerba 2004).

I specifically capture in the following analysis economic sector performances by labour productivity (the economic productivity, labour units per value added) and environmental performance by the ratio of emissions on value added. The environmental performance is namely ‘economic’ in nature, and differs from other proxy indicators such as emissions per employee or emissions themselves. Analyses with those indicators are scope for possible further research.

[4] The WIOD Database is available at: http://www.wiod.org/database/index.htm

[5] Information taken from Eurostat website (http://epp.eurostat.ec.europa.eu/portal/page/portal/microdata/cis).

1.3.1. Comparing major economies in a meso perspective

Table 1.1 exhibits the ranking of the five main countries (Germany, France, Italy, Sweden, Netherlands, the selection of which depends upon relevancy, heterogeneity, data availability) by percentage of adoption of environmental innovation. To provide various insights, some general economic categories are sketched and more specific ones such as some key services, utility sectors that are important insofar they manage natural resources, and heavy industrial sectors that for that reason are under the EU ETS policy aimed at cutting CO2 (potentially inducing innovation).

Looking at the three main eco-innovation indicators mentioned before, it is clear that leaders are Germany and France. Italy achieves the worst performance in most sectors of the five countries, except some ETS sector (manufacture of metal products, manufacture of paper, air transport) and a few services sector (financial services, services for the business economy).

Table 1.12 on the impact of innovation shows that services are plagued even in the EI realm by lower innovation intensity (the well-known 'cost' disease linked to lower productivity). This is relevant both for analyzing sustainability performances along the economy restructure towards services, and for understanding the extent to which increasing vertical integration affects innovation adoption on both sides. The key issue is that mere composition effects, due to innovation weaknesses in some branches and complex transmission of EI across sectors, do not automatically lead to lighter environmental impacts. Marin et al. (2012) show that the total (indirect and direct) emission of services might be close or equal to that of manufacturing.

Table 1.1 shows the expected dominance of Germany in EI adoption, which adds to its highest position in the ranking related to green patents. Germany leadership is driven by the superiority of its industrial core sectors.

The evidence for services is more mixed. Germany does not lead. France is on average the country which presents the best performance, with Sweden and Netherlands also appearing leaders in some cases. In services that are more integrated with industry Germany nevertheless appears to lead in some cases, thus showing the relevance of vertical integration. Though Italy presents a consistent gap concerning CO2 innovation, its role is not negligible in waste technological adoption. The role of packaging waste systems that have been effectively implemented by firms through covenants and schemes that fund recycling and recovery might be investigated in the future.

A final look at 'utility' related sectors shows that while the Germany strength is plausibly confirmed in (highly regulated) areas such as waste management and collection, France plays a major force as well. The gap between France and Italy in this field, where big utilities and public-private company are important players in the production of mixed public services, is worth being further investigated. The role of the (typology of) 'decentralization' of public services (higher in Italy in general terms) and related policies is a possible key issue. Its relationships with environmental innovations have been an overlooked fact.

Table 1. 1 Adoption of Environmental Innovation in years 2006-2008.

		leader CO2 Innov	Italy ranking	leader emission innov	Italy ranking	leader waste reduc inn	Italy ranking
General	Manufacturing	Germany	5	Germany	3	Germany	5
General	All Core NACE activities related to innovation activities	Germany	5	Germany	3	Germany	3
General	Industry (except construction)	Germany	5	Germany	3	Germany	4
Services	Financial and insurance activities	Netherlands	5	France	4	France	3
Services	Financial service activities, except insurance and pension funding	France	5	France	3	France	2
Services	Services of the business economy	Sweden	4	France	3	France	2
Services	Innovation core services activities	Germany	5	Germany	4	France	3
Services	Insurance, reinsurance and pension funding, except compulsory social security	Sweden	5	Netherlands	3	France	3
ETS	Manufacture of basic metals	Germany	5	Germany	3	Germany	4
ETS	Manufacture of basic metals and fabricated metal products, except machinery and equipment	Germany	2	Germany	3	Germany	2

ETS	Manufacture of chemicals and chemical products	Germany	5	Germany	5	Germany	5
ETS	Manufacture of coke and refined petroleum products	Germany	3	Germany	4	Germany	4
ETS	Manufacture of fabricated metal products, except machinery and equipment	Germany	2	Germany	2	Germany	3
ETS	Manufacture of other non-metallic mineral products	Germany	4	Germany	5	France	5
ETS	Manufacture of paper and paper products	Germany	5	Germany	5	Germany	4
ETS	Air transport	Germany	4	Germany	5	France	2
Utility	Sewerage	France	4	Germany	4	Germany	4
Utility	Sewerage, waste management, remediation activities	Sweden	5	Germany	5	France	5
Utility	Waste collection, treatment and disposal activities; materials recovery	Germany	4	Germany	3	France	4
Utility	Water collection, treatment and supply	Germany	4	France	3	France	4
Utility	Water supply; sewerage, waste management and remediation activities	Sweden	5	Germany	5	France	5

Source: CIS Data estracted from Eurostat on line database (in May 2012)

Results of this ranking, prove a relative weakness of Italy in adoption of environmental innovation. The lens with a focus on Italy is relevant insofar it presents one element behind the current problematic unbalances in the EU. The ‘debt crisis’ is largely a problem of diverging economic productivities. Being Italy a big player in the EU, and second industrial country after Germany, one might state that this productivity gap, which certainly has as one of the main driving element a gap in extensive innovation adoption across sectors and regions.

1.3.2. Sector composition and joint performances

The following tables show economic, environmental[6] and eco-innovative performances of (i) main economic sectors (§ 1.3.2.1), (ii) expanding and (iii) shrinking sectors (§ 1.3.2.2). The rationale is to offer a dynamic perspective.

The focus is on main sectors and the most expanding and shrinking ones, to offer a 'structural change and dynamics' perspective of the EU economy.

Selected variables for this analysis are labor productivity (Value Added in 1995 US Dollars / Numbers of employees), CO2 and SOx emissions per unit of Value Added, Energy Intensity (Total consumption of sectorial energy inputs), and the three eco-innovation adoption indicators (increasing energy efficiency, emissions reduction and waste reduction, taken from the CIS).

1.3.2.1. Main sectors

Tables from 1.2 to 1.9 refer to the five major countries selected (Tables 1.2 – 1.4 for main sectors, Tables 1.5 – 1.9 for expanding and shrinking sectors). The appendix shows summary values for all countries (Table 1.12) as well as a table of acronyms (Table 1.11).

Generally speaking, the analysis of figures shows that economic and environmental 'productivities', value per labor and emissions per value, are likely to positively correlate in a dynamic perspective[7]. A positive correlation does not assure sustainability itself. This really depends upon the pace of the decrease. In the cases where value increases more than emissions, relative decoupling is achieved. Only if emissions decrease while the economy (or a sector) grows absolute decoupling is reached. In both cases emissions per value decrease. A descending emissions / value path thus only assure that decoupling is present. Absolute decoupling necessitates emissions to shrink. Radical inventions, innovation diffusion and structural decomposition are needed for this to come by.

The 'Main' sector are selected considering the generated sectorial value added in 2008 (Source: WIOD). Top expanding and top shrinking sectors are chosen by considering the

[6] That capture 'economic efficiency', thus indicators of emissions per unit of value added.

[7] In other terms, this means that one should expect sectors characterised by an high economic productivity (Value added per unit of labour) are also characterised by a low level of emissions (emission per unit of value added). This is a possibility over dynamic scenarios (Mazzanti and Zoboli, 2009), with innovation at the core and behind the correlation.

variation of the generated sectorial value added over 2000 – 2008. The first criterion allows analyzing the country's industrial structure (before the 2009 recession), while the second allows identifying the ongoing transformation in the same economic structure.
In this exercise, sectorial performances by country are compared with the European average: the corresponding cell in the tables below is 'green' if the sector/country performance is better than the European average; while a 'red' cell means that sector/country performs worse than the average. In all the tables of the present section, the calculations refer to the year 2008[8].

Table 1.2 first exhibits main sectors in Italy and Germany, two main industrial players[9]. Both countries are logically mainly composed by services sector, though Germany interestingly presents a still strong and possibly increasing manufacturing sector, that highlights the 'heaviness' of its competitive advantage (which is compensated by higher EI intensity).
Particularly in Italy the larger share of the value added is generated by real estate, which has a higher productivity than Europe and performs better for CO2 and SOX emissions too: this is an example of 'joint' performances. Though not over the average in Europe, we must highlight that the sector is not performing bad in EI terms.
A large share of value added is held also by the construction sector, which performances are generally above the European average. Significant areas are also credit and insurance and wholesale trade. The columns showing the environmental innovation indicators, corroborate the conclusion drawn from table 1 about the weakness in the introduction of environmental innovation in Italy, which is weaker than the EU average.
The German industrial structure is composed mostly by areas related to services but has a large proportion of value added generated by a manufacturing sector, namely the manufacture of computer and electrical machinery which, as will be shown later, turns out to be one of the growing sectors in German economy. It is clear that the adoption of technologies for energy efficiency and reduction of waste generation is widespread in all sectors and above the European average in most cases.

[8] The European mean value is calculated as the un-weighted average of the different variable of interest, at sectorial level for EU27 countries. Other analyses might compare sectors to more specific average benchmarks (e.g. West EU, Euro area, etc..). Preliminary assessments have shown that results are somewhat robust to such sensitivity tests.

[9] In terms of share within EU27, Germany is at 20% in both 2008 and 2011, while Italy shrinks from 13 to 12%. They account for 1/3 of GDP in the extended EU. France share rose from 15 to 16%, while Sweden and The Netherlands are respectively at 3 and 5%. The 5 countries considered, quantitatively amount at more than 50% of EU27 GDP.

Tables 1.3 and 1.4 report the sectorial composition of the economies of France, The Netherlands and Sweden for additional insights.

While the French and the Dutch industrial structure are constituted mainly by services sectors and construction, Sweden shows a great importance of manufacturing sectors as witnessed by computers and electrical machinery in the first row of Table 4. Even if Swedish environmental innovation performances are somewhat unexpectedly below the European average in many cases[10], Sweden confirms to be a case where win win economic environmental performances may jointly appear. Though some more in depth investigations of the EI evidence related to CIS is needed, this is certainly a case where the policy-innovation-performance chain might emerge even at macro scale (Costantini et al. 2013; Costantini & Mazzanti 2012). One should recall that Sweden presents one of the highest environmental taxation share worldwide and an historically high carbon tax.

On the contrary, the productivity of the French main five sectors is lower than the average; on the positive side, emissions and energy intensity are better than in Europe.

The adoption of eco-innovation is widely above the European average (with the exception of sector 7174[11]), confirming the French leadership among the selected countries, as it was evident from Table 1.

Similarly to the French ones, the Dutch sectors obtain better productivity, energy intensity and emissions performance than Europe. In innovation terms, Real estate and renting, R&D and other business activity are above the average.

To sum up, the majority of the value added in the considered economies is produced by the services sector and by construction, as clearly expected. An interesting exception is Germany, which has a large proportion of its value added generated by manufacturing. The electrical machinery sector shows a very good overall performance. Besides the penalization in terms of 'productivity', which partially depends upon some outliers, if table 1.1 and 1.2 are linked the signal is that joint innovation-economic-environmental performance are feasible even at macroeconomic scale. Nevertheless, the German productivity is positive and correlated with very good performance for emission, energy intensity and CO2 abatement.

[10] This is partly due to some missing observation in the CIS data for this country.

[11] The sector 7174 is "Renting of machinery and equipment; computer and related activities; research and development; other business activities"

This case is anecdotal of the EU core specialization in export oriented industry branches. For the green economy to spread over the EU, those leading examples are to be imitated and followed by laggards.

The same comment applies on the leading performances of real estate in France and The Netherlands, and finally construction in France. An even better picture is being highlighted by the service branch 'rent, R&D' and 'credit and insurance' in Sweden, that matches positive trends over the average for economic, environmental and innovation factors.

In the small group of five countries, Germany and France are confirmed leaders in the introduction of environmental innovation, reaching over the European average. Italy not only obtains lower results in economic-environmental performances in most sector branches, but shows an overall weakness in the introduction of environmental innovation compared to the other countries and the European average.

Further analyses are necessary to investigate (i) key eastern emerging players that are on the transition phase, (ii) more micro based data through specific focuses on sectors/countries.

Table 1. 2 Main sectors. Share of value added (2008). Italy and Germany:

Italy - Main Sectors							
Sector	VA/L	Sox/VA	CO2/VA	EN.INT	CIS EN.EFF	CIS CO2	CIS WASTE
70							
7174							
J							
51					Not available	Not available	Not available
F							
Germany - Main Sectors							
70					Not available	Not available	Not available
7174							
51							
3033							
J							

Table 1. 3 Main sectors. Share of value added (2008). France and Netherlands

France - Main Sectors							
Sector	VA/L	Sox/VA	CO2/VA	EN.INT	CIS EN.EFF	CIS CO2	CIS WASTE
7174							
70							
51							
J							
F							
Netherlands - Main Sectors							
7174							
51							
J							
70							
F							

Table 1. 4 Main sectors. Share of value added (2008). Sweden.

Sweden - Main Sectors							
Sector	VA/L	Sox/VA	CO2/VA	EN.INT	CIS EN.EFF	CIS CO2	CIS WASTE
3033							
7174							
70							
51		Not available	Not available				
J							

1.3.2.2. Expanding and Shrinking sectors performances

Tables to 1.5 to 1.9 present results for the top 5 *expanding and the top 5 shrinking* sectors at country level. They have been defined according to the increase/decrease in their share of sectorial VA to total VA between 2000 and 2008. This procedure helps pointing out the ongoing transformation in the economic structure of the five European counties.

In Italy (Table 1.5) the major growing industry in the time span considered is telecommunication, followed by credit and insurance, electricity supply and real estate, each showing better labour productivity, energy intensity and emission performances than Europe. Looking at the columns showing the environmental innovation indicators, we see that once again, Italy is below the European average in every sector. Focusing on the top shrinking sectors, we can see they are mostly related to the manufacturing industry and that the productivity performance and emission have not been very brilliant when compared to the European one.

If attention is held to the shrinking sectors, it is clear that economic-environmental-innovation deficient performances go hand in hand. Failing to address the challenges of environmental policy and the necessary changes posed by the greening of the economy is one of the possible causes of decline. Even historical sectors can in fact reposition themselves in international markets by greening their strategies and processes through innovation investments.

Table 1. 5 Top expanding and top shrinking sectors. 2000-2008. Italy

Italy - Top Expanding Sectors							
Sector	VA/L	Sox/VA	CO2/VA	EN.INT	CIS EN.EFF	CIS CO2	CIS WASTE
64							
J							
E					Not available	Not available	Not available
70							
Italy - Top Shrinking Sectors							
1718							
19							
62							
25							

Germany (Table 1.6), has witnessed a great expansion of water transport sector, which can boast higher productivity than Europe and a lower level of CO2 and SOx emissions; eco-innovation performances too are very good when compared to the EU average, as previously noted in the comparison with major countries. More broadly, transport activities have increased over time and have performed well in the adoption of environmental innovation, as it can be seen in the fourth row of the upper part of table 1.6. Among the expanding sectors computer and electrical equipment is in the second row; one may conclude that Germany's industrial structure differs from other countries since manufacturing not only hold a large amount of value added but is increasing its share over time. Among the shrinking sector manufacturing of wood products, construction, air transport and petroleum products are present. Even if these sectors have progressively reduced their share within the German economy, the adoption of environmental innovation is widespread and up above the European average. The structural re-composition of the economy shows almost a full integration of good innovation-economic and environmental performances.

Innovation is a key issue in the strategy associated to the sectors that are more exposed to the challenges of competitiveness by emerging countries. Their share can shrink due to somewhat natural economic changes, but productivity and wages can be sustained through innovation efforts.

Germany is thus emerging out of the EU average regarding both major and more dynamic sectors. This outstanding performance we know all is part of the EU problem, in the sense that the consequential current account surplus is paradoxically too high at the moment, larger than the Chinese one. Notwithstanding the fact that Germany should probably compensate

Table 1. 6 Top expanding and top shrinking sectors. 2000-2008. Germany

Germany - Top Expanding Sectors							
Sector	VA/L	Sox/VA	CO2/VA	EN.INT	CIS EN.EFF	CIS CO2	CIS WASTE
61							
3033							
64							
63							
Germany - Top Shrinking Sectors							
20							
F					Not available	Not available	Not available
62							
23							

The French situation is shown in table 1.7: expanding sectors are telecommunication, air transport, R&D and other business activities and rubber and plastics. Labour productivity and emission performances are above the European average, even if EI adoption appears to be lower than in Europe, particularly in expanding sectors.

Sectors decreasing the generated value added over time belongs to the manufacturing sector (furniture, leather, textiles); despite that, adoption of environmental innovation is higher than European average, particularly for waste reduction. With respect to manufacturing of electrical apparatus and manufacturing of petroleum products, innovation has been introduced for increasing energy efficiency and CO2 abatement.

Linking this picture to the past economic performance of France, it can be said that the real strength of Germany is really the high value added export oriented manufacturing. On average, manufacturing produces higher value added per employee with respect to most services. Despite the problematic macro performance of France over the recent years, its strength in services seems a strong pillar of the future EU economic development.

In addition, it has to be noticed that the adoption of EI is not an isolated phenomenon, but something that is intrinsically integrated with technological development and organizational change in a broad meaning. The future economic power of the EU and the possibility to effectively integrate economic and environmental for a green sustainable economy depends upon the diffusion of EI in firms and sectors as key assets that complement other techno-organizational innovations, not just end of pipe technologies.

Table 1. 7 Top expanding and top shrinking sectors. 2000-2008. France

France - Top Expanding Sectors							
Sector	VA/L	Sox/VA	CO2/VA	EN.INT	CIS EN.EFF	CIS CO2	CIS WASTE
64							
62							
7174							
25							
France - Top Shrinking Sectors							
61							
1718							
3637							
19							

The Netherlands has seen a greater expansion of services sector (telecommunication, wholesale trade, credit and insurance) as it can be seen in table 1.8. Manufacture is also present, with petroleum products. Expanding and shrinking sector performances are generally below the EU average in terms of eco-innovation adoption. The only exception is credit and insurance, which exhibits an above than average level of CO2 reduction innovation. Despite that, labour productivity and general environmental performances (SOx/VA; CO2/VA) are well above the EU27 level

Overall, The Netherlands performance seems relatively weaker than that of the two major countries Germany and France. Cases of full economic-environmental-innovation joint performances are not observed.

Table 1.9 shows the Swedish situation: as it can be seen, both top expanding and top shrinking sectors are generally better than Europe in terms of productivity and emission.

As in Germany, Sweden is experiencing a growing importance of some manufacturing sectors (petroleum products and electrical machinery) followed by water transport and textiles. Among the shrinking sectors, one can count land transport, pulp and paper, air transport and textiles. Generally speaking, all sectors have introduced some type of eco-innovation with the exception of telecommunication, which performs worse than the EU average as regarding EI. Among shrinking sectors, for instance, ‘land transport presents a very good integrated performance, and similarly to Germany, many shrinking sectors appear to position themselves in competitive niches.

Table 1. 8 Top expanding and top shrinking sectors. 2000-2008. Netherlands

Netherlands - Top Expanding Sectors							
Sector	VA/L	Sox/VA	CO2/VA	EN.INT	CIS EN.EFF	CIS CO2	CIS WASTE
64							
23							
51							
J							
Netherlands - Top Shrinking Sectors							
2122							
19							
3033							
1718							

Table 1. 9 Top expanding and top shrinking sectors. 2000-2008. Sweden

Sweden - Top Expanding Sectors							
Sector	VA/L	Sox/VA	CO2/VA	EN.INT	CIS EN.EFF	CIS CO2	CIS WASTE
23							
3033							
61							
64		Not available					
Sweden - Top Shrinking Sectors							
60							
2122							
62							
1718							

In summary, in the selected countries, manufacturing industry has been expectedly shrinking while the services have risen. As seen above, this general trend is not completely followed by Germany, which sees an expansion in some manufacturing sector, namely the manufacture of machinery and electronic apparatus. It is important to notice that these expanding manufacturing sectors are a case where win-win economic-environmental performances appear achievable through the adoption of innovation. Sweden also shows cases in non-manufacturing expanding sectors and in manufacturing shrinking sectors where win-win performances are likely to emerge if EI is strongly diffused. Moreover, Netherlands and Sweden are bounded to the industry of petroleum products, which increased over time and adopted a significantly share of environmental regulations. Though the less pronounced manufacturing role of France is possibly now penalizing the economy for GDP growth, the good economic-environmental-innovation performance of its services sectors are good signs for the EU, in light of a stronger integration and of a future EU overall competitiveness based on the country's natural and established sector specializations.

For what concerns Italy, both economic, environmental and eco-innovative performances are weak; this is true for both major, top expanding and shrinking sectors. The relative weaker performance is perceivable even if looking at tables in the appendix. Though the ratio GHG/ value added had decreased (recall that decreases, thus improvements of economic efficiency, are driven by cut in emissions and/or increases in economic value), the improvement is lower than that observed for other countries. The productivity weakness matches the difficulty of cutting emissions. This is another point for stressing that sustainable paths towards a greener economy are better achievable if economic and environmental productivities dynamically correlate with the action of (process and product) innovation diffusion behind the scene.

1.4. Decomposition of environmental performance differentials: a shift-share analysis

The evidence proposed in the previous paragraph, show how the selected countries tend to be more environmental efficient than the EU27 average, with respect to the chosen indicators (namely Emission intensity; CO_2/Va and SOX/VA). However, this narrative evidence do not account for the overall environmental efficiency differential between the selected countries and the European average, which will be addressed here thanks to a shift-share decomposition analysis[12]. One of the main advantage of such a technique, which has a long history in growth and urban economics (see among others: Dunn 1960;

[12] Shift share analysis can also be conducted on single sectors, but an aggregate index of the overall country performances is preferred.

Garcia-Milà & McGuire 1993; Esteban 2000) relates to its ability to decompose the factors characterizing different growth differential between a single region or country and a benchmark (for instance the country in which the region is contained or, as in This case, the EU27). In these traditional studies the essential idea was to decompose the growth differential between each regional and the national average, in its two main factors: the region performing generally better than average or a regional specialisation in fast growing sectors. Starting from this approach, Mazzanti & Montini (2009) adopted the shift-share analysis to decompose the total emission efficiency differentials in three components, generally called structural (μ), differential (π) and allocative (α).

If, for instance one consider as indicator of emission intensity E/VA for EU27 (the benchmark), and E_{DE}/VA_{DE} for Germany, the total indicator can be decomposed as the sum of $(E^S/VA^S)*(VA^S/VA)$, where E^S is sectorial emission level and VA^S/VA is the share of sectorial Value Added on Total Value Added for sectors s, where s range from 1 to j (j are the number of sector included in the WIOD accounts, see table 10 in the appendix for the full list of sectors included in the analysis Finally, in the following equations, I use the following notation:

- X is the emission intensity index (where X=E/VA for EU27 and $X_{DE}=E_{DE}/VA_{DE}$ for Germany[13]), and X^S is the sectorial emission intensity. In other term $X = \sum_s P^S X^S$; $X_{DE} = \sum_s P^S_{DE} X^S_{DE}$.
- P^S is the sectorial value added and is define as $P^S=VA^S/VA$.

On this basis, the emission efficiency differential between Germany and the EU27 average can be decomposed and written as X_{DE}-X, in three different components:

1. The structural factor (μ) or industry mix, which indicates the environmental efficiency share attributable to the particular industry mix of the country with respect to the EU average. This effect is given by:

$$\mu_{DE} = \sum_S X^S (P^S_{DE} - P^S)$$

and assume positive (negative) value if the region is specialised in more (less) polluting sectors (according to the chosen indicator).

2. The differential factor (π), which measure that part of differential due to the country being more efficion in abating emissions than the EU average, which is derived as:

$$\pi_{DE} = \sum_S (X^S_{DE} - X^S) P^S$$

[13] Germany is used here as reference, the same principles apply to all other countries.

And assume on positive (negative) values when the country is less (more) efficient in terms of emissions, under the assumption that the country industry mix coindices with the EU one.

3. Finally, the last factor, called allocative (α), is given by the covariance between the previous two components, and represent the contribution to a country energy efficiency given by its specialisation in greener than average countries. It is calculated as:

$$\alpha_{DE} = \sum_{S} (X_{DE}^{S} - X^{S})(P_{DE}^{S} - P^{S})$$

A positive (negative) value of the α_{DE} factor would mean that Germany is specialised in more (less) polluting sectors, in which is less (more) efficient respectively to the EU average.

Interestingly, the sum of these three factors give the exact emission efficiency differential, or in other term X_{DE}-X= $\mu_{DE}+\pi_{DE}+\alpha_{DE}$, which provide an interesting complement to the analysis resented in the previous chapter, enriching the sectorial evidence presented in the previous tables with a broader analysis. The results of this decomposition are presented in the following Table 1.10, which present the emission differential X_i-X and its decomposition for the five analysed countries.

Table 1. 10 Shift-Share Analysis

Country	Pollutant	X_i-X	μ	π	α	Share of the Primary factor	Primary factor (%)
Germany	ET	-3.287	-3.856	42.817	-42.248	48%	π
	Co_2	-0.073	-0.037	**0.109**	-0.145	50%	α
	So_x	-0.524	**0.015**	-0.147	-0.392	71%	α
France	ET	-1.753	-0.524	-0.438	-0.791	45%	α
	Co_2	-0.206	-0.048	-0.169	**0.012**	74%	π
	So_x	-0.498	-0.204	-0.392	**0.098**	56%	π
Italy	ET	**0.689**	-1.402	**4.480**	-2.390	54%	π
	Co_2	**0.037**	**0.015**	**0.072**	-0.050	53%	π
	So_x	-0.333	-0.091	-0.032	-0.211	63%	α
Netherlands	ET	**3.698**	-1.006	**3.781**	**0.923**	66%	π
	Co_2	-0.027	-0.042	**0.014**	**0.001**	73%	μ
	So_x	-0.478	-0.131	-0.463	**0.115**	65%	π
Sweden	ET	-0.753	**10.424**	-1.456	-9.720	48%	μ
	Co_2	-0.217	-0.016	-0.186	-0.016	86%	π
	So_x	-0.458	**0.110**	-0.447	-0.121	66%	π

When considering the aggregate country environmental differential Xi-X previous evidence is clearly confirmed: the country selected tend to perform better than the EU 27 average, as confirmed by the negative sign of most of the coefficients[14]. There are however some interesting exceptions. Netherlands and Italy, in fact, despite being specialised in green sectors (with the exception, for both countries, of "Wholesale Trade", see tables 1.2 and 1.3 of the previous chapter), have an aggregate environmental

[14] All the shift-share indicators are very simple to interpret. A negative sign always means a better than average performance, and a positive sign a worst than average performance

performance below the EU27 average respectively for Energy Intensity (NL) and energy Intensity and CO2/VA (IT). This result, as confirmed by the other column of the shift-share analysis is due by a mix of different Factors. For what concern Emission intensity, both countries are less efficient than EU average, as confirmed by the π factor, which account for the 66% of Netherlands differentials and the 54% of the Italian one. Similarly, also in the case of the Italian CO_2/VA indicator, the below than average performances are due to a mix of the π and α, which account respectively for the 53% and 10% of the total differential. Italy is both specialised in more polluting sectors and has a lower CO2 emission efficiency than EU27. If, on the other hand, the results for the industry mix factor (μ) are analysed some new evidence emerge. Germany and Sweden appear to be slightly more oriented towards SO_X intense sectors, as shown by the positive coefficient associated to this value. The magnitude of this element is however minimal, and account only for the 2% of german differential and the 16% of the Sweden one. More relevant is the case of Emission intensity, which despite being on average more efficient than the benchmark, shw and high specialisation in polluting sectors. Finally, despite the generally very positive performance of Germany, the π factor shows as the Country tend to be less efficient than average for what concern CO2 efficiency. A similar result is found in Netherlands.

1.5. Conclusion

The analyses in this chapter attempt to investigate the static and dynamic performance of EU sectors, trying to understand whether economic, environmental and environmental innovation performances in a joint fashion. I assess the hypothesis that performances may be linked based on a sector-based scrutiny of main 5 EU countries which show cross heterogeneity in the economic structure and accounts for more than 50% of EU27 GDP.

This chapter analyses the role of EI diffusion and its relationships with economic and environmental productivities, descriptively analysing performances for major sectors, top expanding and top shrinking branches. The idea is to provide a general but integrated assessment of how Europe has changed over the past, what performances sectors have shown, and finally whether the recent evolution of the economy is coherent (or not) with a greener, competitive, sustainable economy.

First, it has to be noticed, based on this investigation that economic and environmental performances are effectively potentially interrelated. Examples of integrated innovation-economic-environmental performances appear.

The current EU crisis is not a debt crisis per se, but a crisis that originates from a lack of convergence in relation to innovation and economic productivity performances. It is clear that environmental performances are far from being detached from the above performances. They are strictly integrated in what may be defined an 'overall competitiveness'. Natural sector specialization of the economy matters in explaining competitiveness, but also industrial, innovation and environmental policies are part of the picture (as drivers of the integrated competitiveness).

It is shown how countries have specialized in quite different sectors – within the natural movement towards a service based economy. Though expanding and more competitive sectors show a relative higher likelihood of integrated performances, notice that even in shrinking sectors (typically manufacturing, thus directly more polluting) joint performances are present.

More specifically, some emerging sectors appear those that show the most fruitful amalgamation of economic and environmental dynamics. Innovation confirms to be often a key correlated factor. This is evident for the interesting case of electrical machinery in Germany, a manufacturing sector that has expanded in the EU, and for some cases in services in Germany and France (such as air transport) as well as Sweden (land transport).

It is also worth noting how the overall performance of Germany and France, among others, is relatively better than that of countries plagued by structural productivity and environmental performance gaps due to a fiercer resistance of shrinking sectors to the challenges of international competition. In those countries, even a sector such as textile appears to defend itself through the adoption of innovation.

Expanding sectors lead the current and future re-composition of the economy, but shrinking sectors can produce economic and environmental value even at smaller shares. The importance of integrating economic and environmental performances on both sides of the structural re-composition of the EU economies is then clear for a comprehensive achievement of sustainability and competiveness.

A further extension of this analysis, which can add some new insights with respect to the gap between the northern European countries and the other countries, is to analyse the convergence[15] in emission intensity indicator, in order to better understand if there is an

[15] I refer to convergence as in Barro & Sala-i-Martin (2003)

ongoing process of catching up by countries which lies behind in terms of environmental sustainability.

Appendix

Table 1. 11 Table of acronyms

	Acronym	Description
Sector	1516	Food products, beverage, tobacco
	1718	Textiles and wearing apparel
	19	Leather, luggage and handbags
	20	Wood and products of wood and cork
	2122	Pulp, paper and paper products
	23	Coke, refined petroleum products and nuclear fuel
	24	Chemicals and chemical products
	25	Rubber and plastic product
	26	Other non metallic mineral products
	2728	Basic metals; fabricated metal products, except machinery and equipment
	29	Machinery and equipment n.e.c.
	3033	Office machinery and computers; electrical machinery and apparatus n.e.c.; communication equipment
	3435	Motor vehicles
	3637	Furniture, manufactiring n.e.c.; recycling
	50	Sale, maintenance and repair of motor vehicles and motorcycles
	51	Wholesale trade and commission trade except of motor vehicles and motorcycles
	52	Retail trade, except of motorveichles and motorcycles; repair of personal and household goods
	60	Land transport; transport via pipelines
	61	Water transport
	62	Air transport
	63	Supporting and auxiliary transport activities; activities of travel agencies
	64	Post and telecommunication
	70	Real estate activities
	7174	Renting of machinery and equipment; computer and related activities; research and development; other business activities
	AB	Agricolture and fishing
	C	Mining and quarrying
	E	Electricity, gas and water supply
	F	Construction
	H	Hotels and restaurants
	J	Credit institution and insurance
	L	Public administration and defence; compulsory and social security
	M	Education
	N	Health and social work
	O	Other community, social and personal service activities
	P	Private households with employed persons
	VA/L	Labour productivity
Environmental performance	Sox/VA	Sulphur oxide emission on value added
	CO2/VA	Carbon dioxide emission on vale added
	EN.INT	Energy Intensity
EI (% of firms)	CIS EN.EFF	Reduced energy use per unit of output
	CIS CO2	Reduced CO2 emission (Innovation)
	CIS WASTE	Recycled waste, water, or materials

Table 1. 12 Average values for the EU sectors

Labour Productivity (VA/L)						CO2/Va					SOx/Va				
Sector	**Min**		**Max**		**EU Average**	**Min**		**Max**		**EU Average**	**Min**		**Max**		**EU Average**
Textiles	3.201	ROU	165.877	LUX	39.726	0.009	MLT	0.476	LTU	0.176	0.001	NLD	1.518	EST	0.316
Leather	2.003	ROU	179.434	IRL	37.345	0.016	AUT	0.933	EST	0.244	0.000	AUT	6.618	EST	0.530
Wood	0.755	BGR	94.134	LUX	36.520	0.042	MLT	3.399	BGR	0.338	0.001	SVK	16.638	BGR	1.010
Pulp and Paper	3.290	BGR	240.055	IRL	61.958	0.006	MLT	2.941	BGR	0.420	0.002	LVA	44.916	BGR	2.448
Petroleum Products	0.000	LVA	1067.875	SWE	179.373	0.017	ROU	50.662	DEU	10.695	0.037	CYP	247.898	CZE	41.938
Rubber and Plastics	3.705	BGR	132.122	BEL	51.508	0.009	MLT	1.232	BGR	0.198	0.000	NLD	2.130	EST	0.246
Machinery and Equipment n.e.c.	5.083	ROU	101.460	FRA	50.534	0.004	FIN	3.090	CYP	0.273	0.000	NLD	5.798	EST	0.495
Computer and Electrical Machinery	3.342	BGR	799.828	SWE	105.309	0.000	FIN	6.538	CYP	0.523	0.000	FIN	74.514	ROU	3.079
Other Transport Equipment	5.178	ROU	122.023	AUT	54.935	0.011	PRT	7.639	CYP	0.580	0.000	PRT	5.152	EST	0.551
Wholesale Trade	2.630	BGR	223.962	LUX	56.882	0.006	HUN	0.459	LVA	0.068	0.000	NLD	0.166	LTU	0.024
Water Transport	3.616	SVK	962.712	DEU	113.238	0.018	CYP	31.056	DNK	3.987	0.000	CYP	290.383	DNK	26.014
Air Transport	5.470	HUN	330.889	BEL	93.830	0.004	CYP	27.610	HUN	4.267	0.000	CYP	7.842	EST	0.855
Other Transport Activities	8.001	ROU	121.294	FIN	48.500	0.008	FRA	0.730	ROU	0.146	0.000	NLD	1.234	LTU	0.098
Telecommunication	10.668	ROU	362.828	LUX	110.120	0.003	CYP	0.279	ROU	0.047	0.000	NLD	0.114	HUN	0.015
Real Estate	12.294	BGR	1906.357	GRC	407.760	0.001	AUT	0.232	CZE	0.035	0.000	ITA	0.472	CZE	0.031
Renting, R&D and other Activities	5.897	LTU	80.182	GBR	36.128	0.004	ESP	0.569	BGR	0.101	0.000	SWE	0.260	POL	0.025
Electicity supply	6.108	ROU	363.950	GBR	154.755	0.994	FRA	118.925	EST	15.132	0.263	AUT	607.049	EST	79.531
Construction	2.275	BGR	65.651	BEL	27.766	0.014	GRC	1.799	BGR	0.279	0.002	ESP	4.320	BGR	0.411
Credit and Insurance	10.803	SVK	213.860	DNK	99.903	0.001	PRT	0.503		0.048	0.000	PRT	0.595	BGR	0.029

Source: WIOD, extraction in May 2012.

2. Innovation complementarities and environmental productivity effects: evidences from the EU

2.1. Introduction

The fulfillment of European strategies on emissions and greenhouse targets chiefly depends on the economic and technological evolution of its economic sectors. Technological development and composition effects are pillars of sustainability of production since they both counter balance the economic growth-scale effect. Long run sustainability targets need radical changes in the EU economy. Sector's evolution is pivotal in the greening of the economy, since as the neo Schumpeterian tradition emphasizes, innovation is idiosyncratic at sector level. Both sectors and nationals systems of innovation must be recognized (Malerba et al. 2000). Various analyses have recently focused on economic and environmental dynamics at sector level, by placing innovation at the center of the argumentation (Costantini & Mazzanti 2012; Costantini et al. 2013; Marin & Mazzanti 2010; Costantini & Crespi 2008) .Environmental innovations are a relevant part of the innovation dynamics that should support the integration of competitiveness and sustainability (Borghesi et al. 2012; Kemp & Pontoglio 2011; De Marchi 2012; Horbach 2008). Here the focus is on innovation rather than invention given the importance of diffusion and adoption of innovation practices throughout the economy.

Definitions of eco-innovation (Kemp 2000; Kemp & Pearson 2007) highlight the ecological attributes of individual new processes, products and methods from a technical and ecological perspective. For example, the MEI[16] (Kemp & Pearson 2007) research project defines eco-innovation as the production, assimilation or exploitation of a product, production process, service or business method that is novel to the organization (developing or adopting it) and which results, throughout its life-cycle, in a reduction of environmental risks, pollution and other negative impacts of resources use (including energy use) compared to other relevant alternatives. The inclusion of new organizational methods, products, services and knowledge oriented innovations in this definition differentiates from the definition of environmental technologies as all technologies whose use is less environmentally harmful than relevant alternatives. Along these lines, the drivers of EI both inside and outside the firm's boundaries, in the institutional and economic features of the territory have been analysed (Horbach et al. 2012).

[16] Acronym for Measuring Eco-Innovation

Relevant to this paper are also various streams of literature within the innovation framework, which have hold attention on the role of complementarity among innovation practices (Mohnen & Röller 2005; Mancinelli & Mazzanti 2009; Hall et al. 2012). Nevertheless, despite some advancement even in the environmental innovations framework, the complementarity hypothesis has been seldom analyzed if as a factor behind the improvement of economic and environmental performances (Antonioli et al. 2013). Complementarity is a key strategic element of the firm organizational capabilities. It is also a somewhat irreproducible 'not patented' asset.

Building on theoretical framework by Topkis (1998) and following approaches by Milgrom & Roberts (1990;1995) I want to analyze first if there is complementarity between different kind of innovation (i.e., environmental innovation, organizational innovation, process innovation, product innovation) behind the reduction of CO2 emission, with a focus on environmental productivity as a key indicator (value added on CO2). I investigate whether innovation complementarities are evident for the economy as a whole, and for sub sector groups, specifically manufacturing sector, ETS sectors and geographically divided groups (namely, northern and southern European countries, to test whether innovation gaps of southern countries might be relevant in environmental terms). I want to assess if regulated sector, namely ETS sectors, adopts more environmental innovation to comply with regulation and are able to use complementarities among different kinds of innovation, following the hypothesis by Porter & Linde (1995). Calel & Dechezlepretre (2012), have stated that the EU ETS has actually had effects on the increase in the introduction of environmental innovation, in this case low-carbon innovation; however, in phase one of EU-ETS, process innovation is found to be more likely to occur with respect to product innovation. There is high uncertainty nevertheless on the innovation inducement by ETS (Borghesi et al. 2012; Cainelli & Mazzanti 2013).

The attempt is somewhat original given that the complementarity literature has mainly focused on the drivers of innovations rather than on its effects. Secondly, on the level of performances, the literature has mainly expanded on the side of the economic effects of environmental innovations along the Porter hypothesis (Leeuwen & Mohnen 2013). A specific and original direction is takes, by analyzing the recent effects of innovations and their complementarity on environmental productivity, computed as the ratio of value added on CO2 emission, according to Repetto (1990) and at a sectorial level.

To investigate these issues, that revolve around the notion of complementarity within innovation studies and its effects on environmental productivity, data from the EU

Community Innovation Survey - at sectorial level (available at EUROSTAT website)[17] - and data on sectorial CO_2 emissions (2009 and 2010) available from WIOD[18] are merged, to exploit new EU sector datasets that cover sector, environmental innovation adoption and emission performances. The econometric techniques implemented, takes into account the specific features of ETS sectors, the complementarity among various innovations and the dynamic contents of the innovation-emission relationship at meso level. I first assess the role of innovation taken alone and secondly the evaluate the existence of complementarities among the diverse innovation categories.

The is structured as follows. Section 2 discusses complementarity theory that we adopt and present main research hypotheses. Section 3 comments on the data. Section 4 presents various econometric analyses. Section 5 concludes.

2.2. Environmental productivity and complementarity among innovations: concepts and methods

A relationship of complementarity between two activities implemented by a firm exists when 'doing more' of 'one of them' increases the attractiveness of doing more of the other. Systemic effects arise, "with the whole being more than the sum of the parts" (Roberts 2006, p.37). This has obvious implications on firms' strategies, since the firm's efforts should be targeted toward all the complementary activities. In fact, the change of just some variable may result ineffective if other complementary variables remain unchanged.

Since the seminal applied work by Mohnen & Roller (2005), which was focused on testing empirical evidence of 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[19]. In fact, firms' innovation activity is a

[17]Community Innovation Survey (CIS) are a series of surveys produced by the national statistical offices of the 27 European Union member states, also covering the European Free Trade Association countries and the EU candidate countries. The sixth CIS (2006-2008) collects data on environmental innovation for the first time. Though it is a cross section dataset, it captures a 3 years' time span of EI and is the first CIS survey that has included EI at EU level ever. Community Innovation statistics based data are the main data source for measuring innovation in Europe and are used in academic research as in Horbach et al. (2012) among others who exploit data for Germany.

[18] World Input Output Dataset, stemming from the WIOD FP7 project. It is a sector based economic environmental accounting dataset.

[19] See, among others, Bocquet et al. (2007); Cozzarin & Percival (2006); Gomez & Vargas (2009); Schmiedeberg (2008)

complex outcome deriving from the influence of many factors that are interrelated through complementary relationships, which might give rise to systemic effects.

Remaining within the innovation sphere, deepening empirical analysis of complementarity among different firms' innovation practices is particularly relevant when environmental innovations are involved, especially because of the increasing need to adopt integrated and more complex green strategies and not only "end of pipe" technologies.

This consideration strictly descends from the definition of Environmental Innovation, as presented in the previous section, which is not limited to specific technologies; but also includes new organisational methods, products, services and knowledge-oriented innovations[20].

The importance of adopting integrated strategies of innovations is particularly relevant in complex firms' technologies as CO2 abatement, when compared to mere cuts in emissions such as SOx – NOx (Cainelli & Mazzanti 2013; Marin & Mazzanti, 2010). 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.

Particularly the interest lies in analysing the relationship between firms' environmental performance and different innovation practices, as environmental, process, product and organizational innovations; The agent of the analysis is not the firm, but the sector, for two reasons. The first one lies in the availability of data; the second one is that the sectorial level is the one in which we can fully understand how specific innovation, environmental and economic performance behave and interact (Malerba 2004; Costantini & Crespi 2008; Dopfer 2012).

It is assumed that there is a finite set of economic sectors, indexed by $j = 1,.., J$. In each sector there are a large number of atomistic identical firms, therefore that each sector features one representative firm.

I consider the "environmental performance" of sector j (EP_j) as the sector's objective function and focus on two innovation practices that can affect the sector's *EP* function. One of the two innovation practices is Environmental Innovation (*EI*) and the other one is either product, or process or organizational innovation (*PI*)[21].

[20] The importance of deepening the analysis about the relationship among EI and other innovation practices has already been stressed in Antonioli et al (2013).

[21] The relationship of complementarity may involve more than two variables simultaneously through a chain reaction that starts from a complementarity relationship between two variables and involves a complementarity relationship between one of the two variables and a third variable and so on.

(2.1) $$EP_j = EP_j(EI, PI, \theta_j) \qquad \forall j$$

The problem of sector j is to choose a combination of innovation practices, $(EI, PI) \in I$, which maximize its EP_j function. θ_j represents the sector's exogenous parameters (such as sector-specific environmental policies).

Since 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[22]. Following Topkis (1978;1998) and Milgrom & Roberts (1990;1995), we state that two variables x' and x'' in a *lattice*[23] 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:

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

Or, expressed differently:

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

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'): increasing one of the variables increses the value of the outcome in the second variable as well[24].

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

[22] 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.

[23] 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 &Roberts, 1995, p. 181).

[24] From equations (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'*.

that ensure the existence of interior optima. For example, no divisibility or concavity assumptions are needed, so that increasing returns are easily encompassed.
In this specific case, complementarity between the two different innovation practices may be analysed by testing whether $EP_j = EP_j(EI, PI, \theta_j)$ is supermodular in *EI* and in *PI*. Since each sector is characterized by specific exogenous parameters (θ_j), even if the maximization problem is the same for all the sectors, the *EP* function may result supermodular in *EI* and in *PI* for some sectors, but not for others.

The sector's environmental performance tested, is related to an index of environmental productivity. More specifically, according to the definition of a "single factor measure of environmental productivity" (Repetto, 1990, p. 36)[25], each sector's value added per unit of CO_2 emissions[26]is considered. Obviously, the lower the sector's CO_2 emission value is with respect to the added value, the better its environmental performance, and the higher its environmental productivity (EP_j). Of course, environmental innovations (*EI*) that reduces environmental damages, contributes to environmental productivity. What I want to verify is if *EI* is complementary to other innovation practices (either product, or process, or organizational) when the objective function is environmental productivity.

The aim is to derive a set of inequalities (such as those explicated in equations 2.2 and 2.3) that are tested in the empirical analysis. If in its *EP* maximizing problem, a sector chooses to adopt neither of the two practices, namely $EI = 0, PI = 0$, the element of the set *I* is $EI \wedge PI = \{00\}$. If a sector chooses to adopt both practices, then $EI = 1, PI = 1$ and the element of the set *I* is $EI \vee PI = \{11\}$. Including the mixed cases as well, the elements in the set *I* that form a lattice are: $I = \{\{00\}, \{01\}, \{10\}, \{11\}\}$.
From the above one can assert that *EI* and *PI* are complements and hence that the function EP_j is supermodular, if and only if:

(2.4) $$EP_j(11, \theta_j) + EP_j(00, \theta_j) \geq EP_j(10, \theta_j) + EP_j(01, \theta_j),$$

or:

[25] For extensive discussion on environmental productivity measures and their conceptual background see Mazzanti & Zoboli (2009). The only remark here is that the IPAT framework and its 'statistical' counterpart (STIRPAT) is a general conceptual umbrella (York et al. 2003) to study the economic and innovation determinants of environmental performances.

[26] In this context, environmental productivity is measured as labor or other factors productivity. But then, as well argued in Repetto (1990), since to emissions must be connected costs, rather than benefits, their shadow prices are negative, that is the same sign of the factor inputs.

(2.5) $$EP_j(11,\theta_j) - EP_j(00,\theta_j) \geq \lfloor EP_j(10,\theta_j) - EP_j(00,\theta_j) \rfloor + $$
$$+ \lfloor EP_j(01,\theta_j) - EP_j(00,\theta_j) \rfloor,$$

that is, changes in the Environmental Productivity of sector *j* when both Environmental Innovation and process/product/organizational innovations are increased together are more than the changes resulting from the sum of the separate increases of the two kinds of innovations. Actually, increases in *EP* due to an increase of both *EI* and *PI* from $\{00\}$ to $\{11\}$ are greater (or at least equal) than the sum of increases in *EP* due to separate increases of *EI* and *PI* from $\{00\}$ to $\{10\}$ $(\{01\})$.

To sum up, complementarity between the two decision variables (*EI* and *PI)* exists if the EP_j function is shown to be supermodular in these two variables and this happens when either inequality 2.4 or inequality 2.5 or other derived inequalities are satisfied.

As above mentioned different sectors' exogenous parameters (θ_j) may imply different degrees of complementarity between the two innovation practices (EI_j and PI_j).

In this chapter I am particularly interested in verifying whether the different sector and geographical specificity as well as the strength of environmental regulations to which sectors are exposed, may play a role in the exploitation of the possible relationships of complementarity between environmental innovations and other innovation practices[27]. Therefore, the analysis will be narrowed to some sub sectors of the economy and geographical areas. On the policy side, I assess whether a joint implementation of EI/PI strategy can improve environmental productivity especially in situations of more stringent environmental regulations are present focusing on ETS sectors in some specific analyses[28]. 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 somewhat referred to that of the Porter idea of firm competitive advantages that reside in the firm value chain.

[27] 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.

[28] 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 CO2 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.

On the other hand, one may wonder if sectors less exposed to environmental regulations and hence, could find it more convenient to externalise some innovation practices. This kind of behaviour could even lead to a crowding out effect among some of the innovation strategies under scrutinize and hence to substitutability[29] among them.

Building upon the aforementioned discussion, two main propositions are formulated:

Proposition 1: Complementarity between environmental innovations aimed to ababte CO2 emission and other innovation practices such as organisational and product and process innovations, is crucial to increase environmental productivity.

Proposition 2: Manufacturing and ETS sectors might present more evident signals of innovation complementarity than other sectors, because these are pressed by regulation to find a more radical solutions to be both competitive and sustainable[30]..

2.3. The data

The data used in this analysis comes from three different sources; data on innovation practices (ecoinnovation[31], organizational innovation, product and process innovation) as well as data on ICT adoption are from the sixth Community Innovation Survey (CIS) available on EUROSTAT website. The Community Innovation Survey collects a series of surveys produced by the national statistical offices of the 27 European Union member states, also covering the European Free Trade Association countries and the EU candidate countries. The surveys have been implemented since 1993, on a biannual basis and are designed to obtain information on the innovation activities of enterprises, including several

[29] A substitutability relationship exists if: $EP_j(11,\theta_j) - EP_j(00,\theta_j) \leq [EP_j(10,\theta_j) - EP_j(00,\theta_j)] + [EP_j(01,\theta_j) - EP_j(00,\theta_j)]$, that is, the changes in the sector's environmental productivity are less when both forms of innovation practices (*EI* and *PI*) are increased together than the changes resulting from the sum of the separate increases of the two kinds of practice.

[30] This H2 is also tested by focusing on Northern EU alone, where carbon pricing and climate change policies are historically more stringent (Johnstone et al., 2010).

[31] Only CO2 abatement innovation is considered for the purpose of this work. In the CIS-VI eco-innovation module, a first set of questions asks respondents if they have introduced an innovation with one or more environmental benefits (ECO). Six types of environmental benefits are listed that can occur during the enterprise's use of the innovation(ECOOWN): lower use of materials (ECOMAT), lower energy use (ECOEN), lower CO2 emissions (ECOCO), less use of pollutants (ECOPOL), less soil, water, air or noise pollution (ECOSUB), recycling (ECOREC).

aspects of the innovation process, such as innovation effects, cost and sources of information used. Data are collected at the micro level, using a standardized questionnaire developed in cooperation with the EU Member States to ensure comparability across countries. The sixth CIS (2006-2008) collects data on environmental innovation for the first time. Even if it is a cross section dataset, it captures a 3-year time span of EI and it is the first CIS survey ever to include EI at the EU level . Community Innovation statistics-based data is the main data source for measuring innovation in Europe and is used in academic research as in Horbach et al. (2012) and Borghesi et al. (2012), and Veugelers (2012), which exploit data for Germany, Italy, Belgium, respectively

The second source of data is the World Input Output Database (WIOD), which results from a European Commission funded project as part of the seventh Framework Programme and was developed to analyse the effects of globalization on socio-economic variables and trade, in a wide range of countries (the 27 EU Member States and other 13 major countries in the world, from 1995 to 2009). The WIOD is formed by four different accounts (World Tables, National Tables, Socio Economic Accounts and Environmental Accounts). For the purpose of this work, I used the Socio-Economic and Environmental Accounts, both providing a wide range of economic variables such as value added, employment and CO2 emissions.

Table 2.1 below shows summary statistics and gives a description of the variables considered in this analysis. Building on the concept of environmental productivity (Repetto 1990) the dependent variables VA/CO2_09 and VA/CO2_10 are obtained as the ratio between sectorial value added and sectorial CO2 emission in 2009 and 2010 respectively. It has to be noticed that VA/CO2 is higher in 2010. This means, taking into account the GDP collapse in 2009, that the GDP increase in 2010 was lower overall than the related CO2 emission increase (with respect to 2009).

Innovation practice indicators, originally presented by Eurostat as the share of firms introducing innovation by sector have been dichotomized to obtain an innovation adoption indicator; to compute the binary variable, the country's sectorial value is compared to the average CIS sample sectorial value[32]: if the country value is above the CIS sample average, adoption indicator value is 1 and 0 otherwise; however, since the average is sensible to outliers, to test if the empirical analysis was robust, an innovation indicator using the the

[32] The CIS sectorial average for each country is adjusted by omitting the country sectorial value when making the comparison. For example, for the manufacturing sector in Italy the Italian manufacturing value to the CIS manufacturing value computed without Italy re compared.

third quartile value is also computed (i.e., 25% more innovative firms) for dichotomization[33]. Notwithstanding this, I did not obtain substantially different results.

Four sectorial dummies beyond the innovation adoption indicators are created, namely *manuf, utility*, *other* and *ETS*, and two geographical dummies (*EU_NC* for northern Europe; *EU_SUD* for southern Europe) in order to control for differences within the European area.

In order to test for complementarity, the dichotomised innovation practice indicators are used to create four states of the world for each joint adoption of innovation. For example, concerning the introduction of both eco-innovation and organisational innovation (see Tab. 2.9, in the appendix) I obtained an index for joint adoption (*EI/IO (11)*), two indexes for the adoption of only one of the practices (*EI/OI (10)* stands for EI adoption only; *EI/IO (10)* stands for organizational innovation adoption only) and, finally, I obtained the index *EI/OI (00)* when none of the practices were introduced.

Tables from 2.9 to 2.11 in the appendix show the distribution of the states of the world for the adoption of EI and organisational innovation, and product and process innovation respectively.

[33] Results are collected in Tables 2.12 to 2.14 in the appendix

Table 2. 1 Description of variables

	Observations	***Mean***	***Description***
VA/CO2_09*	496	23.766	Environmental productivity in 2009
VA/CO2_10*	496	21.970	Environmental productivity in 2010
EI	528	0.271	Adoption of environmental innovation for CO2 abatement
Inno_org	528	0.436	Adoption of organizational innovation
Inno_prod	528	0.101	Adoption of product innovation
Inno_proc	528	0.125	Adoption of process innovation
Emp08	431	11,3252	Number of employees per sector
Vaemp	500	84.589	Labour productivity
ICT	379	0.172	Percentage of adoption of information and communication technology
Manuf	528	0.542	Manufacturing sector dummy
Utility	528	0.042	Utility sector dummy
Other	528	0.3333	Other services sector dummy
ETS	528	0.25	ETS sectors dummy
EU_NC	528	0.227	Northern European dummy (Belgium, Germany, Netherlands, Finland, Sweden and France)
EU_SUD	528	0.182	Southern European dummy (Cyprus, Malta, Italy and Portugal)

2.4. Econometric evidence: complementarity analysis

2.4.1. Model specification and methodology

The following equation, presents the specification which results will be used to investigate complementarity. The same regression is run using data either in 2009 or in 2010.

(2.6)
$$\frac{VA}{CO2} = \alpha + \beta_1 Labour\ Prod. + \beta_2 ICT + \beta_3 (EI,PI)_{11} + \beta_4 (EI,PI)_{10} + \beta_5 (EI,PI)_{01} + \beta_6 (EI,PI)_{00} + \varepsilon$$

The inclusion of labour productivity as a main covariate follows Mazzanti & Zoboli (2009) and aims at capturing sector heterogeneity and general heterogeneity in economic conditions. ICT investments are included to further control for a 'new economy' factor that can absorb relevant cross section heterogeneity. The last four elements in the equation, finally introduce the states of the world for which EI and other 'innovations' are both present (11) or are not adopted (00), or they are adopted in isolation of each other (10, 01). I use OLS as an estimation procedure and correct for heteroskedasticity in usual fashion[34]. The parsimonious regression aims to mitigate collinearity (see the appendix for correlations). Since labour productivity and ICT are not correlated – this recalls the 'Solow productivity paradox' – these are both inserted as main factors. Geographical dummies such as EU North, South, East and West are included to further control for heterogeneity. Regressions are carried on a dataset of 496 units.

To investigate the presence of significant interactions, a Wald test is carried to test if the inequality in equation 2.5 is satisfied. Null hypothesis of the Wald test is that there is not significant differences between $[(EI,PI)_{11};(EI,PI)_{00}]$ and $[(EI,PI)_{01};(EI,PI)_{10}]$. Afterwards, the sign of the inequality is computed; if positive, the function is supermodular and complementarity between innovation practices is found; if negative, the function is submodular and substitutability is present.

2.4.2. Results

[34] See for reference Verbeek (2012)

Tables 2.2 – 2.7 below summarise the main findings with respect to the existence of complementarity between EI and techno-organisational innovation adoption, when the mean value is used for dichotomization, as explained in section 2.3. The null hypothesis tested (recall Proposition 1 and 2 in section 2.2) is the absence of pair-wise complementarity between innovation adoption to reduce CO2, and other types of techno-organisational innovation.

Tables 2.2 to 2.4 present tests for the EU as a whole. The absence of significant Wald statistics is informative of the absence of any complementarity (or substitutability, in case of significant negative inequality) in the adoption of EI and other techno-organisational innovations in the EU. It is worth noting that 2010 shows higher values in the tests. Nevertheless, evidence is clear and does not support the idea that complementarity is behind CO2 cuts by sectors. Also in ETS sectors, complementarity is not used as a radical innovation strategy to cut CO2 (Borghesi et al. 2012; Rogge & Hoffmann 2009; Rogge & Hoffmann 2010). Tables 2.12 to 2.14 in the appendix, add some sort of sensitivity analysis by using an alternative method to construct the set of binary variables that are needed to set the complementarity test (namely to create the states of the world)[35]. The highest value found is for the pair EI-product innovation (the ETS sectors in 2010). Nevertheless, the test value does not reach a minimum threshold of 10% significance.

The pair EI-product innovation is of interest, because it possibly represents the most radical and effective strategic movement towards environmental productivity increases. On the one hand, EI are primarily aimed at cutting CO2, while product innovation generally delivers the highest output in terms of value added creation (e.g. investing in new special steel production of high international market value while rearranging environmental technology for this production to abate emissions, an example that is coherent with anecdotal evidence for Scandinavian countries, for example)[36].

Tables 2.5 to 2.7, sketch the evidence for Northern countries alone (we include The Netherlands, Belgium, Germany, France, Sweden and Finland, on the basis of data

---

[35] Results are robust to the variation of the method adopted to 'dichotomise' the innovation variable in order to set the 4 states of the world. 4 main options are considered: mean, median, first quartile and a specific mean, where the difference between country sectorial values and the EU sector average value is taken. This is calculated without considering that country's value.

[36] This paper do not explicitly cover the role of policies behind innovation adoption and emissions cuts. policy heterogeneity is captured by country dummies and geographically/sector oriented analysis. The inclusion of specific policy factors is scope for further research.

availability[37]). It is well known that innovative and environmental performances of the EU North are on average different. Historically speaking, some northern EU countries promptly reacted to the second oil shocks by innovation and energy mix reshuffling. This socio-economic and policy 'reaction' has brought about different CO2 trends between areas (Mazzanti & Musolesi 2013). Thus, complementarity in relation to innovations might also be a factor that presents different features in various parts of the EU. In fact, that the only cases where complementarity shows up, that is when the null of no complementarity is rejected, is for the pairs EI-product innovation (both 2009 and 2010) in manufacturing (first quartile dichotomisation generates similar outcomes), and EI-process innovations in 2009.

Two main facts needs to be highlighted: First, even in the depth of recession, technology complementarity supported relatively better-integrated economic-environmental performances. Then, at the dawn of the weak economic restart in 2010, complementarity between EI and product innovations of potential high value given its cuts to emissions and generation of spaces of high value added export in international markets – characterises the EU North.

The core manufacturing heart of Europe thus beats in a more innovative way. Heavy but competitive sectors in the North respond with higher environmental and economic performances. It is not possible to assess here whether this is a pillar of future EU sustainability. It depends upon whether technology is able to compensate for scale effects. I stress that within the technological domain, how innovations are tied to each other and 'organised' in their integrated design might matter, because it can affect European socio economic sustainability of economic dynamics – which correlate to environmental performances to a larger extent. This is possibly the key problem of EU integration at the moment. The path to a greener economy, which is engraved in current EU policies and targets, is a chance to mitigate divergences. However, there is the risk that the path towards a greener economy might widen divergences further[38].

The somewhat gloomy outcome presented, if one thinks of the potential core role of innovation (complementarity) in achieving goals of sustainablity and competitiveness, is

[37].As examples, Spain and the UK as well did not implement the EI part of the CIS6 questionnaire, which was not compulsory.

[38] Tables 2.15 to 2.17 in the appendix illustrate how the values of the tests for southern Europe (Cyprus, Malta, Italy and Portugal) are dramatically different, which denotes a general lower degree of complementarity of firms and sectors in the laggard countries (in terms of economic, environmental and innovation dynamics).

nevertheless coherent with related evidence on innovation dynamics taking place in the EU before and after the down turn. First, recent studies by the EEA (2013) shows that the EU's decrease in emissions has been driven more by a changing composition of the economy than by the role of technology. If on the one hand Eco Innovations characterise about 45% of EU firms as the EU Horizon plan declares; complementarity among various (EI) innovation practices is confined to very specific elements and pairs according to Regional evidence on the other (Antonioli et al. 2013).

Secondly, within the debate that analyses the links between the crisis and its innovation and economic effects, Filippetti & Archibugi (2011), use the EU Innovation scoreboard dataset to analyse the effect of the crisis on EU innovation performances, finding that the downturn has strongly negatively affected caching up in eastern areas, and concluding: "We have also seen that the countries that were relatively less affected are those with a stronger National systems of innovation. Switzerland, Sweden, Finland, Germany and Austria will emerge from this crisis with a relatively stronger innovative capacity, while the United Kingdom and France, and to a larger extent, the Southern European countries, are likely to lose additional relative positions. Within a perspective of increasing integration, this calls for a stronger and cooperative innovation policy at the European level not only in good times but especially in bad times" (p.189)[39]. National systems of innovation emerge as relevant, namely the northern EU model that has its roots in a strong support to (green) innovations and a huge surplus in its current accounts (Costantini & Mazzanti, 2012). This is a winning model if one look at the economic-environmental performances of northern EU countries. Moreover, it has created divergent gaps between southern and northern areas. Whether it is true that southern countries own a large share of responsibility for not having increased their investments in innovation and strengthened their environmental policy commitment in the last 15 years, this divergence of economic (and environmental) performances runs the risk of tearing the different parts of the EU apart. More investments in innovation and strengthening of environmental policy in the south, and more (public) investments in the north to support aggregate demand would help rebalance the macroeconomic economic-environmental equilibrium of the EU.

[39] Linking the evidence to the commented paper, one should be pessimistic about the future scenario. In fact, innovation impacts relate to the pre-crisis innovation diffusion. If that diffusion further benefits the northern EU after the downturn, given different 'innovation' and institutional reactions, one should expect additional divergences in the value added/CO_2 performance in the current decade. In absence of new data, for the time being even if one only considers factors at an anecdotal level , this scenario seems likely to happen (EEA, 2013a).

Table 2. 2 Complementarity test; all sectors (mean value variable dichotomisation)

All sectors				
Innovation Practice Variables	VACO2_09		VACO2_10	
Mean value used for dicotomisation	Wald Test	Sign of the linear combination (b11+b00)+(-b10-b01)	Wald Test	Sign of the linear combination (b11+b00)+(-b10-b01)
EI Organisational Innovation	0.01	≤0	0.08	≥0
EI Process Innovation	1.70	≤0	1.72	≤0
EI Product Innovation	1.95	≤0	2.10	≤0

Table 2. 3 Complementarity test; manufacturing sector (mean value variable dichotomisation)

Manufacturing				
Innovation Practice Variables	VACO2_09		VACO2_10	
Mean value used for dicotomisation	Wald Test	Sign of the linear combination (b11+b00)+(-b10-b01)	Wald Test	Sign of the linear combination (b11+b00)+(-b10-b01)
EI Organisational Innovation	0.33	≤0	0.16	≤0
EI Process Innovation	0.39	≥0	2.55	≥0
EI Product Innovation	0.78	≤0	0.39	≤0

*** significant 1%; ** significant 5%; * significant 10%. The null is absence of complementarity. “b” are the coefficients of the regression associated with the states of the world (1 or 0, respectively presence or absence of a defined input in the functions that studies complementarity)

Table 2. 4 Complementarity test; ETS sector (mean value variable dichotomisation)

Innovation Practice Variables	VACO2_09		VACO2_10	
Mean value used for dicotomisation	Wald Test	Sign of the linear combination (b11+b00)+(-b10-b01)	Wald Test	Sign of the linear combination (b11+b00)+(-b10-b01)
EI Organisational Innovation	0.03	≥0	0.11	≥0
EI Process Innovation	0.74	≥0	0.56	≥0
EI Product Innovation	1.36	≤0	1.67	≤0

Table 2. 5 Complementarity test; all sectors; northern Europe (mean value variable dichotomisation)

All sectors				
Innovation Practice Variables	VACO2_09		VACO2_10	
Mean value used for dicotomisation	Wald Test	Sign of the linear combination (b11+b00)+(-b10-b01)	Wald Test	Sign of the linear combination (b11+b00)+(-b10-b01)
EI Organisational Innovation	0.61	≤0	0.42	≤0
EI Process Innovation	1.59	≤0	1.58	≤0
EI Product Innovation	1.14	≥0	1.12	≥0

*** significant 1%; ** significant 5%; * significant 10%. The null is absence of complementarity. "b" are the coefficients of the regression associated with the states of the world (1 or 0 ,respectively presence or absence of a defined input in the functions that studies complementarity)

Table 2. 6 Complementarity test; manufacturing sector; northern Europe (mean value variable dichotomisation)

Manufacturing				
Innovation Practice Variables	VACO2_09		VACO2_10	
Mean value used for dicotomisation	Wald Test	Sign of the linear combination (b11+b00)+(-b10-b01)	Wald Test	Sign of the linear combination (b11+b00)+(-b10-b01)
EI Organisational Innovation	0.88	≥0	0.86	≥0
EI Process Innovation	2.81*	≥0	0.65	≥0
EI Product Innovation	2.85*	≥0	2.81*	≥0

Table 2. 7 Complementarity test; ETS sectors; northern Europe (mean value variable dichotomisation)

ETS				
Innovation Practice Variables	VACO2_09		VACO2_10	
Mean value used for dicotomisation	Wald Test	Sign of the linear combination (b11+b00)+(-b10-b01)	Wald Test	Sign of the linear combination (b11+b00)+(-b10-b01)
EI Organisational Innovation	0.57	≥0	0.52	≥0
EI Process Innovation	0.00	≥0	0.00	≥0
EI Product Innovation	1.21	≥0	1.20	≥0

*** significant 1%; ** significant 5%; * significant 10%. The null is absence of complementarity. “b” are the coefficients of the regression associated with the states of the world (1 or 0, respectively presence or absence of a defined input in the functions that studies complementarity)

2.5. Conclusions

The paper adds new insight on the effects of innovation on environmental productivity by exploring original EU sector data through the lens of complementarity theory, which is a consolidated technique used to study the drivers of innovation. Complementarity among innovation practices points to relatively radical ways of tackling the challenge of cutting CO_2 and creating economic value, since it entails both an investment in diverse practices and a full reorganization of firm strategy. The hypothesis is that though the implementation of more innovations occurs at a higher cost – tangible and intangible – the consequential outcome, which is driven by increasing returns to the scale and redesign of the organization, might bring about higher performances. Complementarity is an asset in which to invest resources. Moreover, environmental innovations are in that 'complementarity' context which is implicitly of a more radical nature, since they are not adopted in isolation, as well-known end of pipe technologies often are. The existence of complementarity thus highlights somewhat radical ways of managing innovations. These are needed to tackle climate change, for which end of pipe solutions are rather useless.

Complementarity is not a delusion, but it is a rare fact in the real world of innovation adoption. It is rare because even if it potentially brings about value in terms of asset specificity, rent capture by creation of 'irreproducible' assets and full technological redesign, it is costly and forward looking (Dosi et al. 2006).

Complementarity is not characterising the EU economy for what concerns the 'use' of EI as a driver of CO_2 reduction. Investing in EI and other techno-organisational practices has not led to environmental productivity improvements. Evidence does not change when narrowing down on manufacturing and ETS sectors that are subject to stricter regulations. The outcome is robust to diverse specifications of the underlying variables used to frame the 'complementarity setting'. Results are similar for what concerns environmental productivity in 2009 and 2010: innovation actions that took place before 'the crisis' (2006-2008) have not produced significant effects on economic-environmental performances.

The only case where a complementarity arises is for northern EU manufacturing sectors that seem to integrate coherently environmental and product innovations to support sustainability and competitiveness. It is likely that the lack of integrated innovation adoption behind environmental productivity performance is a signal of the current weaknesses economies face in tackling green economy challenges. Incremental rather than more radical strategies have so far predominated. This is probably not sufficient when looking at long run economic and environmental goals. The specific EU case study also shows risks of further divergence in both economic and environmental performances between innovative northern countries and southern EU laggards.

Environmental and innovation policies might introduce the notion of complementarity more explicitly in funding and regulatory schemes.

However, the period under consideration has specific features in of itself and innovations could take more time to exert their effects, this is a possible proof that the mild decrease in GHG emissions the EU has experienced hugely depends upon incremental innovations, which are in addition not integrated among themselves in a significant goal-oriented way. The lack of integration documents the non-radicalness of the innovation strategy that economic sectors have pursued so far, at least on average. As additional support to this statement, only when interacting do EI and technological process innovation statistical tests on complementarity move up, though never reaching a full significance.

Further research might extend the analysis to firm level assessment of innovation effects on emissions. It is also worth considering the future exploitation of new CIS waves and emissions sector data to assess whether these results are partially influenced by the idiosyncratic economic setting that characterised 2009 and 2010.

Appendix

Table 2. 8 Correlation matrix

	VA/CO2 (2010)	EI	Inno_org	Inno_prod	Inno_proc	Labor product	ICT
VA/CO2 (2010)	1						
EI	0.0047	1					
Inno_org	0.0033	0.2095*	1				
Inno_prod	0.0305	0.0417	0.1756*	1			
Inno_proc	0.0451	-0.0191	0.4804*	0.0677	1		
Labor product	0.2982*	0.0309	0.1102*	0.1268*	0.0683	1	
ICT	0.0087	-0.1803*	-0.0571	-0.0792	-0.0264	-0.0712	1

*significant 5%

Table 2. 9 EI and Organisational Innovation. States of the world

	EI/OI (11)	EI/OI (10)	EI/OI (01)	EI/OI (00)
Mining and quarring	3.91%	7.14%	3.61%	3.55%
Manufacturing	5.47%	4.29%	4.82%	5.67%
Food, beverage and tobacco	3.13%	8.57%	7.23%	3.55%
Textile and leather	4.69%	4.29%	4.82%	4.96%
Wood products	4.69%	5.71%	6.02%	3.55%
Paper products	6.25%	0.00%	3.61%	4.96%
Coke and petroleum	0.78%	4.29%	4.82%	2.13%
Chemical	4.69%	2.86%	6.02%	4.26%
Rubber and plastic	5.47%	2.86%	6.02%	4.26%
Non metallic mineral products	5.47%	5.71%	4.82%	4.96%
Metal and fabricated metal products	4.69%	5.71%	4.82%	5.67%
Computer and electrical equipment	4.69%	4.29%	6.02%	4.96%
Machinery and equipment	4.69%	4.29%	3.61%	6.38%
Motor vehicles and transport equipment	3.91%	2.86%	6.02%	5.67%
Other manufacturing	4.69%	5.71%	6.02%	4.26%
Waste, water and electricity	7.03%	5.71%	1.20%	4.96%
Construction	2.34%	0.00%	1.20%	3.55%
Wholesale and retail trade	3.91%	4.29%	2.41%	4.26%
Transport and storage	4.69%	8.57%	6.02%	3.55%
Accomodation and food	0.78%	1.43%	1.20%	0.71%
Information and communication	4.69%	0.00%	2.41%	4.96%
Financial activities	3.91%	8.57%	4.82%	4.26%
Real estate	0.78%	1.43%	2.41%	0.71%
Other professional activities	4.69%	1.43%	0.00%	4.26%
	100%	100%	100%	100%

Table 2. 10 EI and Product Innovation. States of the world

	EI/Prod Innov (11)	EI/Prod Innov (10)	EI/Prod Innov (01)	EI/Prod Innov (00)
Mining and quarring	0.97%	8.33%	1.61%	4.93%
Manufacturing	6.80%	3.57%	6.45%	5.63%
Food, beverage and tobacco	2.91%	7.14%	8.06%	3.52%
Textile and leather	5.83%	2.38%	1.61%	7.04%
Wood products	5.83%	4.76%	3.23%	4.93%
Paper products	3.88%	3.57%	4.84%	2.82%
Coke and petroleum	0.97%	2.38%	1.61%	2.82%
Chemical	3.88%	3.57%	6.45%	3.52%
Rubber and plastic	4.85%	4.76%	4.84%	4.93%
Non metallic mineral products	5.83%	5.95%	3.23%	4.93%
Metal and fabricated metal products	3.88%	5.95%	8.06%	4.93%
Computer and electrical equipment	3.88%	5.95%	9.68%	4.23%
Machinery and equipment	3.88%	5.95%	8.06%	4.23%
Motor vehicles and transport equipment	2.91%	3.57%	8.06%	5.63%
Other manufacturing	5.83%	4.76%	4.84%	4.93%
Waste, water and electricity	6.80%	7.14%	1.61%	4.93%
Construction	0.97%	1.19%	3.23%	2.82%
Wholesale and retail trade	2.91%	5.95%	1.61%	4.23%
Transport and storage	6.80%	4.76%	3.23%	3.52%
Accomodation and food	0.97%	1.19%	1.61%	0.70%
Information and communication	5.83%	0.00%	4.84%	4.23%
Financial activities	7.77%	3.57%	1.61%	5.63%
Real estate	0.97%	1.19%	1.61%	0.70%
Other professional activities	4.85%	2.38%	0.00%	4.23%
	100%	100%	100%	100%

Table 2. 11 EI and Process Innovation. States of the world

	EI/Process Innov (11)	EI/Process Innov (10)	EI/Process Innov (01)	EI/Process Innov (00)
Mining and quarring	3.23%	6.00%	4.05%	3.47%
Manufacturing	6.45%	4.00%	4.05%	6.25%
Food, beverage and tobacco	5.38%	4.00%	4.05%	5.56%
Textile and leather	6.45%	3.00%	4.05%	5.56%
Wood products	4.30%	6.00%	5.41%	4.17%
Paper products	4.30%	4.00%	6.76%	3.47%
Coke and petroleum	1.08%	2.00%	2.70%	1.39%
Chemical	3.23%	5.00%	4.05%	4.86%
Rubber and plastic	5.38%	4.00%	5.41%	4.86%
Non metallic mineral products	2.15%	9.00%	8.11%	3.47%
Metal and fabricated metal products	5.38%	5.00%	9.46%	3.47%
Computer and electrical equipment	4.30%	5.00%	2.70%	6.94%
Machinery and equipment	4.30%	5.00%	2.70%	6.25%
Motor vehicles and transport equipment	4.30%	3.00%	5.41%	6.25%
Other manufacturing	4.30%	6.00%	6.76%	4.17%
Waste, water and electricity	7.53%	6.00%	2.70%	4.17%
Construction	2.15%	1.00%	0.00%	4.17%
Wholesale and retail trade	4.30%	4.00%	4.05%	3.47%
Transport and storage	6.45%	5.00%	5.41%	4.17%
Accomodation and food	1.08%	1.00%	1.35%	0.69%
Information and communication	3.23%	3.00%	5.41%	3.47%
Financial activities	5.38%	5.00%	4.05%	4.86%
Real estate	1.08%	1.00%	1.35%	0.69%
Other professional activities	4.30%	3.00%	0.00%	4.17%
	100%	100%	100%	100%

Table 2. 12 Complementarity test; all sectors; (first quartile variable dichotomisation)

All sectors				
Innovation Practice Variables	VACO2_09		VACO2_10	
IIIQ value used for dicotomisation	Wald Test	Sign of the linear combination (b11+b00)+(-b10-b01)	Wald Test	Sign of the linear combination (b11+b00)+(-b10-b01)
EI Organisational Innovation	0.38	≤0	0.31	≤0
EI Process Innovation	1.93	≤0	2.11	≤0
EI Product Innovation	1.35	≤0	1.13	≤0

Table 2. 13 Complementarity test; manufacturing sector; (first quartile variable dichotomisation)

Manufacturing				
Innovation Practice Variables	VACO2_09		VACO2_10	
IIIQ value used for dicotomisation	Wald Test	Sign of the linear combination (b11+b00)+(-b10-b01)	Wald Test	Sign of the linear combination (b11+b00)+(-b10-b01)
EI Organisational Innovation	1.00	≥0	0.98	≥0
EI Process Innovation	0.07	≥0	0.07	≥0
EI Product Innovation	1.45	≤0	0.92	≤0

*** significant 1%; ** significant 5%; * significant 10%. The null is absence of complementarity. “b” are the coefficients of the regression associated with the states of the world (1 or 0, respectively presence or absence of a defined input in the functions that studies complementarity)

Table 2. 14 Complementarity test; ETS sector; (first quartile variable dichotomisation)

ETS					
Innovation Practice Variables		VACO2_09		VACO2_10	
IIIQ value used for dicotomisation		Wald Test	Sign of the linear combination (b11+b00)+(-b10-b01)	Wald Test	Sign of the linear combination (b11+b00)+(-b10-b01)
EI	Organisational Innovation	0.47	≤0	0.63	≤0
EI	Process Innovation	0.32	≥0	0.33	≥0
EI	Product Innovation	2.03	≥0	2.20	≥0

Table 2. 15 Complementarity test; all sectors; southern Europe

All sectors					
Innovation Practice Variables		VACO2_09		VACO2_10	
Mean value used for dicotomisation		Wald Test	Sign of the linear combination (b11+b00)+(-b10-b01)	Wald Test	Sign of the linear combination (b11+b00)+(-b10-b01)
EI	Organisational Innovation	0.54	≥0	0.30	≥0
EI	Process Innovation	0.03	≥0	0.06	≥0
EI	Product Innovation	0.42	≥0	0.47	≥0

*** significant 1%; ** significant 5%; * significant 10%. The null is absence of complementarity. “b” are the coefficients of the regression associated with the states of the world (1 or 0, respectively presence or absence of a defined input in the functions that studies complementarity)

Table 2. 16 Complementarity test; manufacturing sector; southern Europe

Manufacturing				
Innovation Practice Variables	VACO2_09		VACO2_10	
Mean value used for dicotomisation	Wald Test	Sign of the linear combination (b11+b00)+(-b10-b01)	Wald Test	Sign of the linear combination (b11+b00)+(-b10-b01)
EI Organisational Innovation	1.71	≥0	1.84	≥0
EI Process Innovation	0.03	≥0	0.01	≥0
EI Product Innovation	0.19	≤0	0.20	≤0

Table 2. 17 Complementarity test; ETS sector; southern Europe

ETS				
Innovation Practice Variables	VACO2_09		VACO2_10	
Mean value used for dicotomisation	Wald Test	Sign of the linear combination (b11+b00)+(-b10-b01)	Wald Test	Sign of the linear combination (b11+b00)+(-b10-b01)
EI Organisational Innovation	0.47	≥0	0.45	≥0
EI Process Innovation	0.00	≥0	0.01	≥0
EI Product Innovation	1.19	≤0	1.15	≤0

*** significant 1%; ** significant 5%; * significant 10%. The null is absence of complementarity. “b” are the coefficients of the regression associated with the states of the world (1 or 0, respectively presence or absence of a defined input in the functions that studies complementarity)

3. Carbon dioxide emissions-innovation relation: Evidences from the European countries

3.1. Introduction

The control of polluting emissions is a primary concern for society throughout the world, particularly in the advanced economies. Efforts by governments have focussed especially on the promotion of measures aimed to reduce carbon dioxide emissions (hereafter CO2), which are responsible of the 60% of the total anthropogenic exhalations (Cole et al. 2008). In the context of the United Nations Framework Conventions on Climate Change, the Kyoto protocol (United Nations 1998) has been a cornerstone in the path to a lower emission world, committing its parties towards the achievement of internationally binding targets of emission reduction. In the EU, the Kyoto agreement has been acknowledged in the late 2000s with the set-up of the European Emission Trading Scheme[40] (hereafter, EU-ETS).

EU-ETS covers the heavy branches of the manufacturing sector (production of coke and petroleum, chemicals, basic metals, non-metallic minerals and pulp and paper) as well as the energy sector and recently, also the air transport sector.

Policy is considered pivotal towards the achievement of a better environmental sustainability of firms' production since it enables managers and entrepreneurs to internalise the cost of the environmental externality. Moreover, following the hypothesis stated by Porter & Van der Linde in the mid '90s, regulation might trigger the development and the adoption of innovation, as a way through which firms can achieve both a better environmental performance and a better business performance. The emphasis in Porter & Van der Linde (1995), has often been placed on the adoption of Environmental Innovation, which is defined as a new product or a new production process which results in a reduction of environmental impacts (in terms of pollution as well as in terms of other negative consequences), if compared to the relevant alternatives (Kemp & Pearson 2007). As a consequence, a glowing branch of literature investigated the magnitude and the significance of policy as a driver of environmental innovation (among others: Brunnermeier & Cohen 2003; Lanoie et al. 2008; Nesta et al. 2014; Kemp & Pontoglio

[40] International emission trading systems are one of the three mechanism provided by the agreement for the achievement of the emission reduction target, together with clean development mechanism (CDM) and joint implementation (JI).

2011). However, literature contributions on the effect of innovation on CO2 emissions is rather scarce, especially concerning a sectorial level of analysis; this chapter constitutes an attempt to gain some perspective on the impact of innovation on sectorial' environmental performances.

Environmental performance is measured using data on CO2 emissions; innovation is measured through two different indicators, which uses patent data according to Griliches (1998) and Popp et al. (2011). The first one collects patent applications in all technology fields; the second collects only patent applications in environmental technologies; value added is also a relevant variable included in the model (Dinda 2004); finally, an indicator capturing the effect of policy is added to investigate the effects on emissions. In addition, a term of interaction between policy and technology is included to test the hypothesis that the effects of regulation are stronger in countries and sectors that have a high knowledge base, since these can better exploit the opportunities created by the policies.

The dataset is built of a sample of 14 branches of the manufacturing sectors for 13 EU countries, during the period 1995-2007.

The chapter is structured as follows. Section 3.2 reviews the factors affecting CO2 emission and at the same time states the research hypothesis; section 3.3 describes the data and the creation of both policy and innovation indexes; section 3.4 defines the specifications of the model; section 3.5 comments on results and section 3.6 concludes.

3.2. Factors affecting CO2 emissions

3.2.1. Technological Change

The relationship between innovation and environmental performance is at the centre of this analysis. The hypothesis which underlies the model presented in section 3.3, is that the introduction of innovation and environmental innovation in the manufacturing sector is actually reducing polluting emissions, by improving the efficiency of the productive process of firms in that industry. Moreover, many authors highlighted how the improvements in technology and science need to be considered as an important lever when addressing environmental issues and climate change (Abbott 2009). With respect to the specific case of emission reduction, Jaffe, Newell, & Stavins (2002), underline that the process of technological change has an impact both in terms of economic performance of firms and in terms of environmental impact and that "potentially, emission reduction is associated with faster diffusion of existing technologies" (Jaffe et al., 2002, p. 48);

Moreover, the adoption of a sectorial perspective allows to explore the centre of the generation and the diffusion of innovation and to discover strengths and weaknesses underlying the overall country performance, in both economic and environmental terms (Malerba 2002).

Also Popp et al. (2009), argues that environmental technology can actually help to reduce the environmental clean-up costs while Lanzi (2013), states that investment in innovation development and adoption, by firms and economic agents, allows to improve the use of energy and to reduce polluting emissions, while at the same time preserving the level of economic performance of countries and sectors; in a paper by Carrión-Flores & Innes (2010), where the relation between environmental innovation and environmental regulatory standards in the US is studied, the authors found evidence of a negative and significant effect of environmental patents on emissions. Finally, Wang et al. (2012), who investigate the causal relation between energy technology patents and CO2 emissions, found that while fossil-fuelled technology patents have no effect on emission reduction, patents oriented to carbon-free technology can actually help reducing CO2 in eastern China. Concerning studies on emissions reduction in Europe, Costantini et al. (2013) study the economic drivers influencing the spatial distribution of environmental performance in Italy, at sectorial level; the authors finds that, when focussing on the geographical aspect of environmental performance, technology spillovers are highly relevant in explaining environmental performance.

Based on this previous evidences, the following hypothesis will be tested:

Proposition 1. Innovation and particularly environmental innovation, negatively affects CO2 emissions in Europe.

3.2.2. Economic growth

Another relevant variable to be considered is income, measured in this paper in terms of value added produced by sector. Among the extensive literature on the relation between environmental performance and income, the Environmental Kuznets Curve (hereafter, EKC) is of particular interest for this analysis. As described by Dinda (2004) in an extensive literature on this theory, EKC outlines the relation between environmental performance and income per capita as an inverted-U long term relationship: at an initial stage of economic development (e.g., in a stage where agriculture is the predominant activity), concerns and information on environmental degradation are low and there is a lack in the availability of environmental technologies. However, as economies grow and develops, the structural change towards a service and information-oriented industry together with the increasing availability of new and green technologies, raise the awareness about the environmental deterioration, giving rise to a process of improvement of environmental quality.

Thus, an inverse relationship between increasing sectorial value added and the level of CO2 emissions over time is hypothesised. In this regard, chapter 1, describes the joint economic and environmental performances of five European countries, with the purpose to describe the relationship among the shifting of these economies from a manufacturing-based to a services-based economies, their adoption of environmental innovation and their environmental performance. The findings suggest that economic and environmental performance can be actually interrelated and that both defines the trajectory of the overall competitiveness of a country, especially in emerging sectors where innovation confirms itself as a key factor. Also in a paper by Marin & Mazzanti (2010), which considers the relation between environmental performance and labour productivity from a sectorial viewpoint, evidence of decoupling trends for CO2 is offered.

On the contrary, other authors have found different empirical results on the relationship between economic and environmental performance: in a recent analysis by Andersson & Karpestam (2013), the authors decompose the relation between CO2 and economic activities for a sample of Advanced Economies; analysis' results show that both energy intensity and carbon intensity have declined over time but this variation is not sufficient to compensate the rise of CO2 emission because of a scale effect, at least in the short run. Also Duarte et al. (2013), found that growth in production due to increasing demand have absorbed almost all the benefits of technological improvements, especially in heavy branches of the manufacturing sector.

Notwithstanding these controversial results, the following hypothesis is outlined:

Proposition 2: Economic growth has a positive influence on environmental performance, namely, lower level of CO2 corresponds to a higher level of value added produced by industry

3.2.3. Environmental Policy and its interactions with Technological Change

As widely acknowledged in the literature (Jaffe & Palmer 1997; Brunnermeier & Cohen 2003; Carrión-Flores & Innes 2010) environmental policy is considered one of the most relevant factor in the achievement of the desired environmental performance.

Policy mechanism mainly acts through two channels: first, it brings about the problem of addressing negative externality caused by the production activities of firms, charging producers for the damage they cause to the environment (Popp et al. 2009); secondly and more interestingly, following a theory by Porter & Van der Linde (1995), it triggers the adoption of environmental technologies by firms, allowing them to simultaneously reduce their environmental impact and to increase their profit through a more efficient productive process. This happens because, following the authors, regulation signals to the firms that there is a potential waste of resources which can be improved through the adoption of new technologies. In order to be applied to the empirical analysis, the hypothesis has been given three different interpretations: first, the so called weak Porter Hypothesis, which states that properly crafted environmental regulation spurs the adoption of environmental technologies; the strong Porter Hypothesis, which states that for firms, the introduction of innovation can often more than offset the cost of having complied with the environmental policy; finally, the narrow Porter Hypothesis, which states that flexible policy instruments, give greater incentive to innovate to the firms.

The weak definition of the Porter Hypothesis is the one that best suits the purpose of this analysis; in fact policy can indirectly act on CO2 emission level by inducing technological improvements in the firms. Moving from these premises, the following proposition will be tested:

Proposition 3. The presence of a sectorial policy, such as EU-ETS, has a negative impact on the level of CO2 emissions.

This hypothesis is further extended by incorporating a term of interaction between environmental policy and technological change because it is supposed that policy effects are stronger in counties and in sectors which have an high knowledge base, because they can better exploit the opportunities created by the policy. The final hypothesis to be tested is:

Proposition 4. Technological change and policy are complementary in reducing CO2 emissions.

3.3. Data description

To investigate the hypothesis outlined in the previous section, data from different sources were gathered together, for the time span 1995-2009. Data on CO2 and value added by sector are collected for 13 European countries[41] from the World Input Output Database (WIOD), which is the output of a European Commission's project in the Seventh Framework Programme, and which collects data from 1995 to 2009 for both the EU27 countries and other non-European relevant countries. Data on total and green patent applications are drawn from the OECD REGPAT database, which collects patents applications to the EPO and PCT filings for more than 5.500 regions, including non-OECD countries. Finally, data on environmental policies at sectorial level are collected from the *OECD database on instrument used for environmental policy*. I considered all the available instrument (namely, deposit-refund schemes, taxes, emission trading, voluntary approaches, environmental subsidies, fees) to build a policy index as explained in section 3.3.1. Table 3.1 summarises the variables included in this analysis.

The dependent variable, *co2* is the level of CO2 emissions by sector in each year of the panel. *Value added* is the generated value added at sectorial level. Value added is deflated using the level of prices in the first year of the panel (i.e., 1995). *Patents stock* and *Green patents stock* are the two indicator of innovation, which are built as stock of previous knowledge, according to Popp et al. (2011); this approach allows, on one hand to account for the fact that innovation has not an instantaneous effect on the level of emissions and, on the other, that previous knowledge has a decreasing impact on the actual level of emissions. The variable *Patents stock* refers to the stock of knowledge built using patents application in all technology fields, while *Green patents stock* refers to the stock of knowledge built using patent applications in environmental technologies field only. The stock have been computed, for both indicators, according to the following formula:

[41] Austria, Belgium, Germany, Denmark, Spain, France, United Kingdom, Greece, Ireland, Italy, Netherlands, Portugal, and Sweden

$$\text{K Stock}_{i,t} = \sum_{s=0}^{\infty} e^{-\beta 1(s)}\left(1 - e^{-\beta 2(s+1)}\right)\text{PAT}_{i,j,t-s}$$

where the rate of knowledge obsolescence is represented by β1 and the rate of knowledge diffusion is represented by β2. As it is commonly adopted in the literature (see, for example Popp et al. 2011), the rates are 0.1 and 0.25 respectively

3.3.1. Environmental policy index

Data in the *OECD database on instrument used for environmental policy*, are available either at country or at sectorial level. Data are collected in tables where for each country are provided detailed information on each of the different instrument categories[42], in a time span which ranges from the early 1970s to 2013; for each policy categories names of schemes (the policy instrument) and sub-schemes (the several parts of which the policy instrument is composed) are reported[43]. Tables collecting instrument categories for the sectorial level are not specifying the year of introduction of the regulation, therefore to build the dynamic standardized policy index included in this analysis, I merged data on both sectorial level policies and country level policies using the sub-schemes' names. Secondly, I extracted six dummy variable representing the six policy instruments included in the OECD database; these variables take a value of 1 if the policy is in force in a certain year and in a certain sector, while they have a value of 0 otherwise. Thirdly, I created a policy index as the sum of all the policies in force in a given year in a particular sector; the index could range from 0 (the sector is not covered by any policy) to a maximum of 6 (all the policy instruments are in force in the sector). Finally, I standardized the policy index according to the formula $Z = {(X-\mu)}/{\sigma}$ to obtain the standardized indicator.

Table 3.4 and Figures 3.10-3.11 in the appendix, offers some more insights on the instruments categories and depict the distribution of policy instruments across countries and sectors, respectively.

[42] Namely, deposit-refund schemes, taxes, emission trading, voluntary approaches, environmental subsidies, fees and charges.
[43] For example, grants and soft loans under a subsidy scheme would be separate sub-schemes

Table 3. 1 Description of variables

Variable	Description
co2	CO2 emission in metric tons
Patents stock	Stock of total patents applications to the EPO in all technological fields
Green patents stock	Stock of patents application to the EPO in environmental technologies
Value added	value added generated per year, deflated at 1995 prices. Sectoral level. Added as a control variable
Policy index	Standardized policy indicator which includes deposit-refund schemes, taxes, ETS, voluntary approaches, environmental subsidies (by sector); source: OECD database on instruments used for environmental policy
Technology*Policy	Interaction between policy index and patents stock
Green tech*Policy	Interaction between policy index and green patents stock

3.3.2. Data description

Figure. 3.1 depicts the aggregated trend of CO2 emission (on the left side) and value added (on the right side) in the European countries considered, from 1995 to 2009. Concerning CO2, the plot shows that there is not a steadily decreasing or increasing pattern in emissions, rather the trend quickly fluctuates between maximum and minimum peaks, at least from 1996 to 2002; only around year 2005, emissions begin to decrease steadily, even if at a slow rate. Finally, in the last years of the 2000s, there is a sudden and deep fall in emission, consequent to the economic crises occurred. Some insights underlying the aggregated trend, is offered in the Appendix, in Figures 3.3 and 3.4 showing CO2 emission variation trend at country level and Figures 3.5 to 3.7 displaying the variation at the sectorial level. As it can be noticed in figures A1 and A2, only a few countries such as Germany, France and the Netherlands show on average a steady level of emission; on the contrary, countries as Greece and Ireland present a wider range of fluctuation in emissions. Also at the sectorial level, there is not a well-defined pattern in emission variations as highlighted in Figures 3.5 to 3.7; only some of the ETS sectors, namely Coke and Petroleum, Chemical and non-Metallic Mineral Products, experience a smaller fluctuation and generally keep emissions around the initial values.

The trend of the aggregated value added is shown in the right side of Figure 3.1; value added is decreasing at the end of the '90s and reaches its minimum at the beginning of the last decade, probably because of the burst of the Internet Bubble, which had caused a crisis at the beginning of the 2000. However, around 2003-2004, value added starts to increase again.

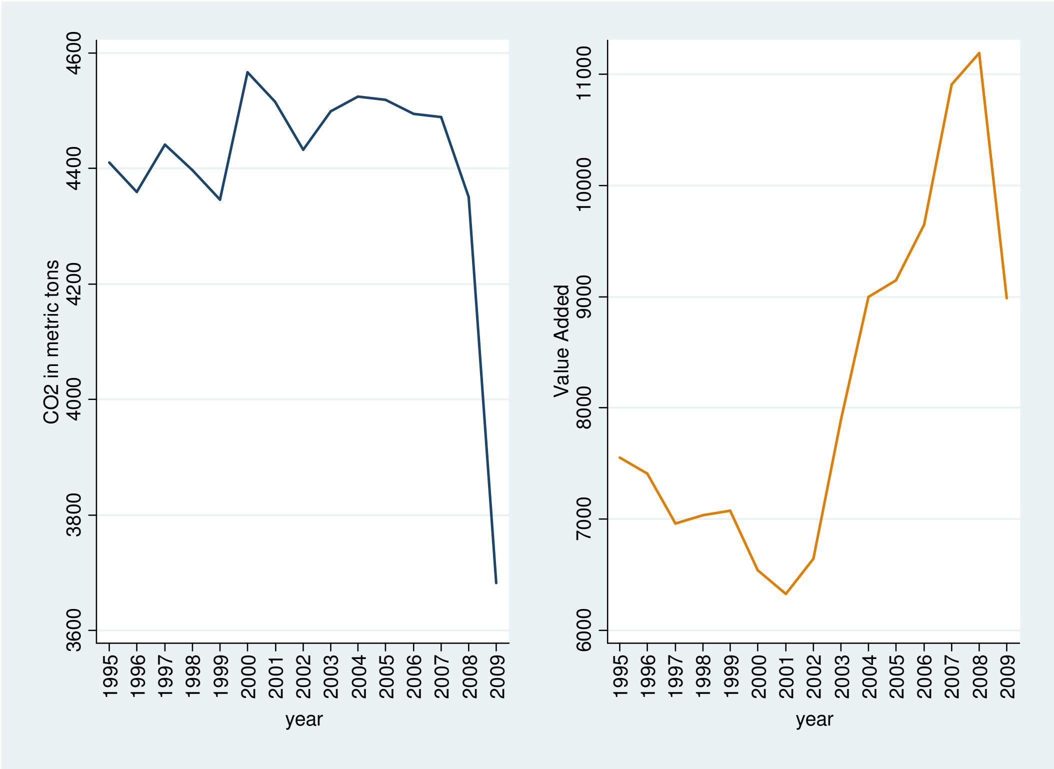

Figure 3. 1 Aggregated CO2 emissions and Value Added variation in 1995-2009

The correlation between CO2 emissions and value added by sector, are shown in Figures 3.8 to 3.12 in the appendix, where a quadratic and a linear regressions curves are added to the scatterplots to roughly describe the relation between the two variables. There are three main considerations that can be drawn: first, there are sectors such as basic metals, textile, and leather which always show a positive correlation between CO2 and value added. Secondly and conversely, there are sectors where there is evidence of a change in the sign of the correlations, from positive for lower level of value added to negative for higher levels. This change in the sign of the correlation, is clearer for sectors such as rubber and plastic, transport equipment and recycling. Finally, in sectors subject to EU-ETS (namely, basic metals, non-metallic mineral products, coke and petroleum, paper and cardboard and chemical products), increasing emissions usually corresponds to increasing value added and evidences of an inversion in the sign of these correlations are rather weak; this, however is not surprising, since these sectors are the most polluting ones.

Figure 3. 2 Aggregated total patents and green patents variation in 1995-2009

Figure 3.2, shows trend for patents application in all technology fields (left side) and patents application in environmental technologies (right side). Both trends are increasing in the period considered even if they slightly slowdown in the mid-2000s. Some other insight is offered in Figures 3.13 and 3.14 in the appendix, which show total and green patents application in ETS and non-ETS sectors respectively, in order to highlight any difference in the patenting activity of the heaviest branches of the manufacturing sectors. Patents applications in sectors covered by ETS are overall lower than those in other sectors, even if this might be because ETS sectors are only 5 out of the 14 considered. Concerning total patents applications, the trend in both groups of sectors move togheter, the ETS one laying below the non-ETS one. With regards to green patents applications, it is interesting to notice that applications in environmental technology in the mid 90's were greater for ETS sectors than for non-ETS ones; around 2002, green patents applications in the ETS group are greatly decreasing, while those in the non-ETS steadily increase. However, starting from 2003, the trends are increasing and move together.

3.4. Methodology

3.4.1. Model specifications

In order to test the hypothesis outlined in section 3.2, two model's specification has been built: the first one, which I called base specification, includes only the lagged value of patents stock (either total patents or green patents), value added and the the standardized policy indicator, as shown in equation 3.1.

(3.1) $$CO2_{i,t} = \alpha + \beta_1 patent\ stock_{i,t-1} + \beta_2 value\ added_{i,t} + \beta_3 policy_{i,t} + \eta_{i,t}$$ [44]

A second specifications, also includes the lagged term of interaction between policy and technology (either *Technology*Policy* or *Green tech.*Policy*) as presented in equation 3.2.

(3.2) $$CO2_{i,t} = \alpha + \beta_1 patent\ stock_{i,t-1} + \beta_2 value\ added_{i,t} + \beta_3 policy_{i,t-1} + \beta_4 (patent\ stock_{i,t-1} * policy_{i,t}) + \eta_{i,t}$$

To check for the robustness of the results and in order to capture the effect of omitted time varying variables, also a specification including year and sectorial interactions (equation 3.3) and individual time trend (equation 3.4) respectively, are considered as alternative ways to check for the robustness of the results obtained through specification in equation 3.2.

(3.3) $$CO2_{i,t} = \alpha + \beta_1 patent\ stock_{i,t-1} + \beta_2 value\ added_{i,t-1} + \beta_3 policy_{i,t-1} + \beta_4 (patent\ stock_{i,t-1} * policy_{i,t}) + \beta_5 year * sector_{i,t} + \eta_{i,t}$$

(3.4) $$CO2_{i,t} = \alpha + \beta_1 patent\ stock_{i,t-1} + \beta_2 value\ added_{i,t-1} + \beta_3 policy_{i,t-1} + \beta_4 (patent\ stock_{i,t-1} * policy_{i,t}) + \beta_5 trend_{i,t} + \eta_{i,t}$$

[44] Patent stock refers either to the total patents applications stock or to the green patents application stock. The term ηi,t is the composite error term: $\eta_{i,t} = u_i + \varepsilon_{i,t}$, the right side of the equation representing the variance due to the unobserved heterogeneity and to the stochastic error term respectively.

3.4.2. Estimation

Since it is assumed that there exists sector specific unobserved factors which can affect the level of CO2 emissions (i.e., there exists correlation between the regressors and the unobserved heterogeneity term in the composite error) the specifications in equations from 3.1 to 3.4 are estimated through a fixed effect regression[45], which allow to estimate a within transform[46] of the model, to eliminate the effect of the unobserved heterogeneity.
To check for the consistency of the fixed effect coefficient, as it is usual in the literature I also perform a random effect estimates. Differently from the fixed effect model, the assumption here is that there is no correlation between the regressors and the composite error term (i.e., there is not unobserved heterogeneity).
Finally, Hausman[47] test is performed to choose the consistent estimate. Under the null hypothesis of no correlations between the explanatory variables and the composite error term, the consistent estimate is the random effects one. Conversely, if the test rejects the null hypothesis, then unobserved heterogeneity exits and the consistent estimate is the fixed effects one.

3.5. Results

This section presents results of the fixed effects estimation, since the Hausmann test systematically rejected the null hypothesis of non-correlation between the regressors and the composite error term, the consistent estimates is the fixed effect one. Tables collecting results of the random effects estimation are reported in the appendix (Tables 3.5 and 3.6)
All estimates are computed with robust standard errors.

The first set of results concerns the specifications in which the stock of total patents application is included. Table 3.2 shows results for both the base specification (left column) and for the specification with the interaction term (right column). Lagged level of patent stock is used following the principle that the effects of an increase in technological knowledge today are delayed, namely, it is more likely that new knowledge produces its

---

[45] See for reference Cameron & Trivedi (2005)
[46] Within transform has the form:

$$y_{i,t} - \bar{y}_i = a + b_i(x_{i,t} - \bar{x}_i) + (\varepsilon_{i,t} - \bar{\varepsilon}_i)$$

Where the term ui is eliminated since it is a constant.
[47] The Hausman test statistic is:

$$S = (b_{FE} - b_{RE})[var(b_{FE}) - var(b_{RE})]^{-1}(b_{FE} - b_{RE})$$

effects in the future rather than today. The lagged total patents variable is significant in both specifications and has the a negative effect on CO2 emissions; as hypothesized, technological change can lower polluting CO2 emissions Also policy index is significant in both but the effect is lower when the interaction is included . This may be because in the base specification, policy index partially captures the effect of the interaction. However both hypothesis 3 and 4 are confirmed in this analysis having both policy index and interaction a negative effect on emissions. The effect of value added is significant but positive, contrary to the expectations. However, it has to be noticed that the focus of the analysis is on the emissions of the manufacturing sector and has outlined in section 3.3.1, there are not evidences of an inverted-U relation in all the manufacturing branches.

Table 3. 2 Fixed effect regression results. Total patent used as technological change indicator.

	Base co2	Interaction co2
Lag total patent stock	-0.163*** (0.0585)	-0.217*** (0.0496)
Value added	0.0281** (0.0116)	0.0363*** (0.0126)
Policy index	-212.0** (89.70)	-138.1* (83.27)
Tech*Policy		-0.190*** (0.0618)
_cons	4273.4*** (79.89)	4240.9*** (82.54)
N	2811	2811

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

Table 3.6 in the appendix, collects results of the specifications which includes the effects of unobserved time varying factors. The sign and significance of the lagged patents stock, of value added and of the policy and technology interaction term are not altered and the magnitude of the coefficient of these variables slightly increases with respect to their values in Table 3.2. Only the effect of policy index in uncertain, since it is significant only in the specification using the individual trend, since the inclusion of the dummy variables rules out the effects of the policy indicator.

Table 3.3 shows results of the specification which includes the green stock of patents instead of total patents.

Results are less good than expected: in fact, green patents are weakly significant in the base specification (left column of Table 3.3) and not significant at all in the specification including the green technology and policy interaction term (right column of Table 3.3). A possible interpretation is that the total patent indicator collects environmental effects of technological change more than the green patents indicator. In fact, while the total patent indicator collects both new products and new technologies relative to all technological domain, by definition green patents are relative only to brand new products which are defined as green and to the green sector. As a consequence it is the overall knowledge base proxied by the total stock of applications to influence environmental emission and not only the green one. Several process innovations filed by non-green firms, may have a positive effect on environmental performances if their adoption increases the overall environmental productivity. End-of-pipe abatement technologies for example, are often produced by brown sectors, and do not enter in the final count of green patent.

Also policy loses significance with respect to the previous tables, while value added is not significant when the green knowledge stock is included. Policy and green technology interaction, however, is still a significant driver, with the expected negative sign.

Table 3.8 in the appendix show results including time and sector interaction and individual trend respectively. Significance of the interaction between policy and technology still hold even if it is weak, while policy remains significant only when individual time trend are added. Finally, green technology is no longer significant.

Table 3. 3 Fixed effects regression results. Green patents used as technological change indicator.

	Base	Interaction
	co2	co2
Lag green patent stock	-1.786*	-1.195
	(0.947)	(1.072)
Value added	0.0152	0.0117
	(0.00997)	(0.0104)
Policy index	-209.6**	-169.0*
	(89.21)	(85.99)
Green tech*Policy		-1.807**
		(0.913)
_cons	4343.7***	4365.9***
	(68.68)	(65.00)
N	2811	2811

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

3.6. Conclusions

The analysis in this chapter is aimed to shed light on the role of innovation in the improvement of the environmental performance.

To do so, I investigated the effect of innovation and environmental innovation on CO2 emissions level, in the period 1995-2009. Moreover, I also framed other three research hypothesis: i) economic growth negatively impacts on CO2 level (i.e., there exist a ECK-like relation); ii) environmental policy can help in lowering CO2 emissions; iii) there is a negative effect of the interaction between policy and technology in determine reduced CO2 levels. Thus, the variables included in this analysis are CO2 emission level, gross domestic product, patents applications in all technology fields and green technology fields respectively and a standardized policy indicator. Data were gathered from different sources, namely WIOD, REGPAT and the OECD database on instrument used for environmental policy. All data are collected at the sectorial level.

Results highlighted that technological change has a significant and negative impact on CO2 levels and that, this evidence is stronger for total patents application than for green patents applications. An explanation lies in the different definition of a green invention with respect to a general invention; while the latter includes brand new inventions in both product and process technologies, the latter tends to include mainly product innovation. Therefore, because CO2 abatement is more related to the implementation of new process technologies than to new and green products, the coefficient of green patent applications tends to underestimate the impact of green innovation on CO2 emissions. A second important result is that even if policy indicator is not always strongly significant in the analysis, its interaction with technology (both is case of total technology and green technology) always is. Therefore it can be concluded that introducing environmental policy increases the effect of technology, i.e., policy effects are stronger in sectors which have an higher knowledge base, because they can better exploit the opportunities created by regulation in the light of an induced innovation framework. Finally, value added is significant when the total knowledge stock is considered while when the analysis is narrowed to the green knowledge stock only, this variable is no longer significant.

The analysis in this chapter, which yields some interest insight on the relation between technological change and environmental performances, can be further improved by implementing a dynamic longitudinal model, since it is rational to assume that the current level of CO_2 depends on its previous values (i.e., CO_2 is persistent). Therefore, the lagged level of the dependent variable should be included in the model. In the second place, it may be necessary to find instrumental variables for the environmental policy index. Similarly to the issues presented in Downing & White (1986) and Nesta et al. (2014), the successful introduction of an environmental policy can actually reduce CO_2 emission level and may cause a further tightening of the policy target or standard, to additionally reduce air pollution

Appendix

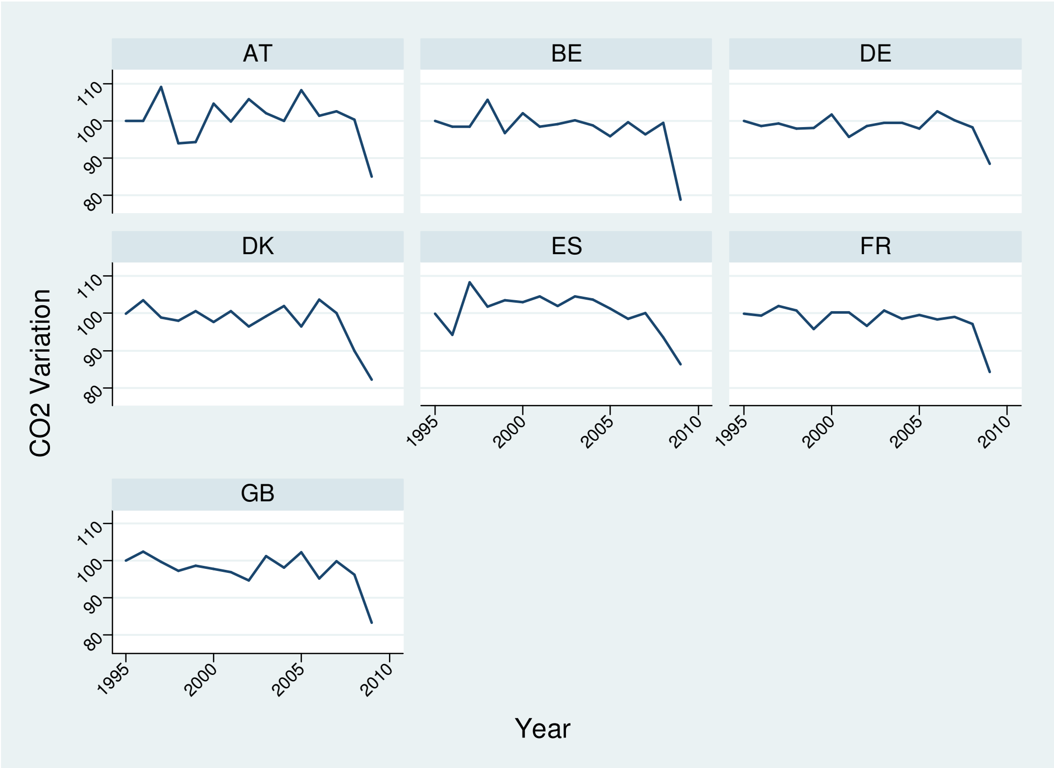

Figure 3. 3 CO2 variation by country. 1995-2009. (1)

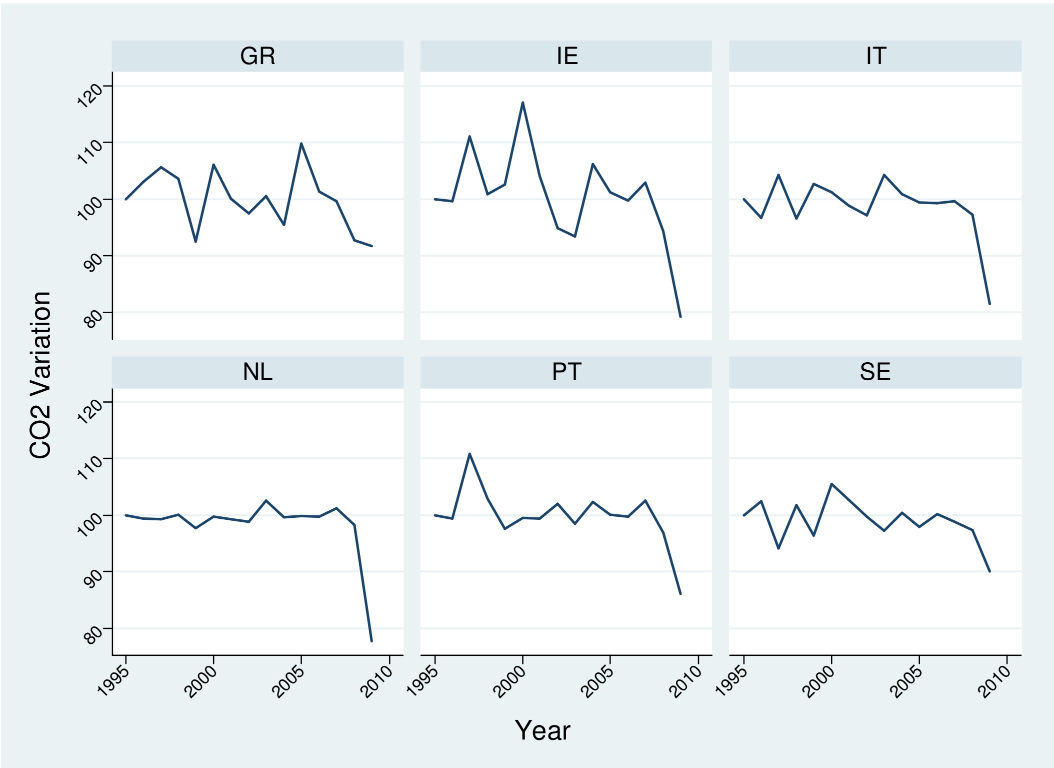

Figure 3. 4 CO2 variation by country. 1995-2009. (2)

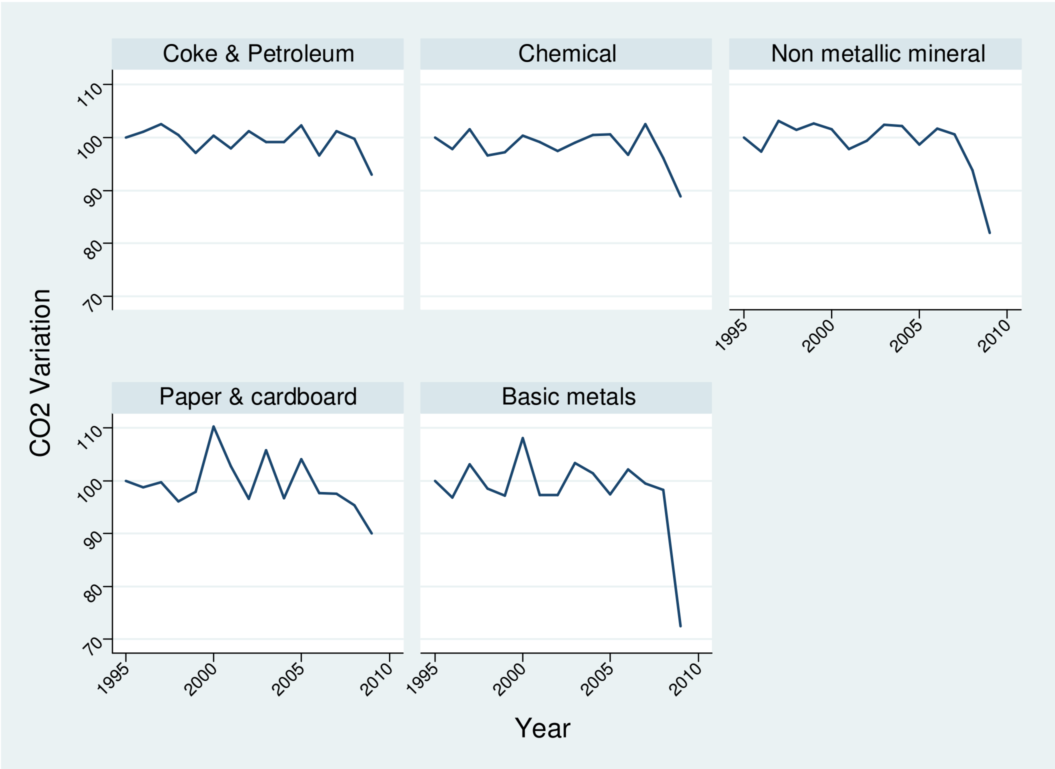

Figure 3. 5 CO2 variation by sector. 1995-2009. (1)

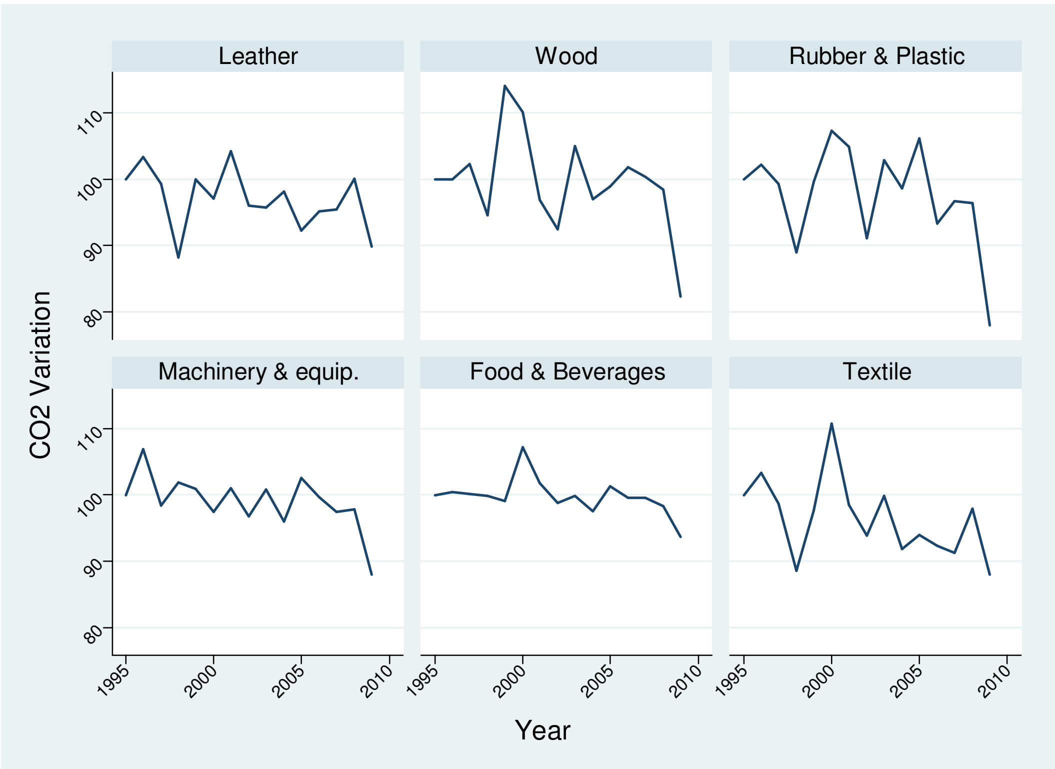

Figure 3. 6 CO2 variation by sector. 1995-2009. (2)

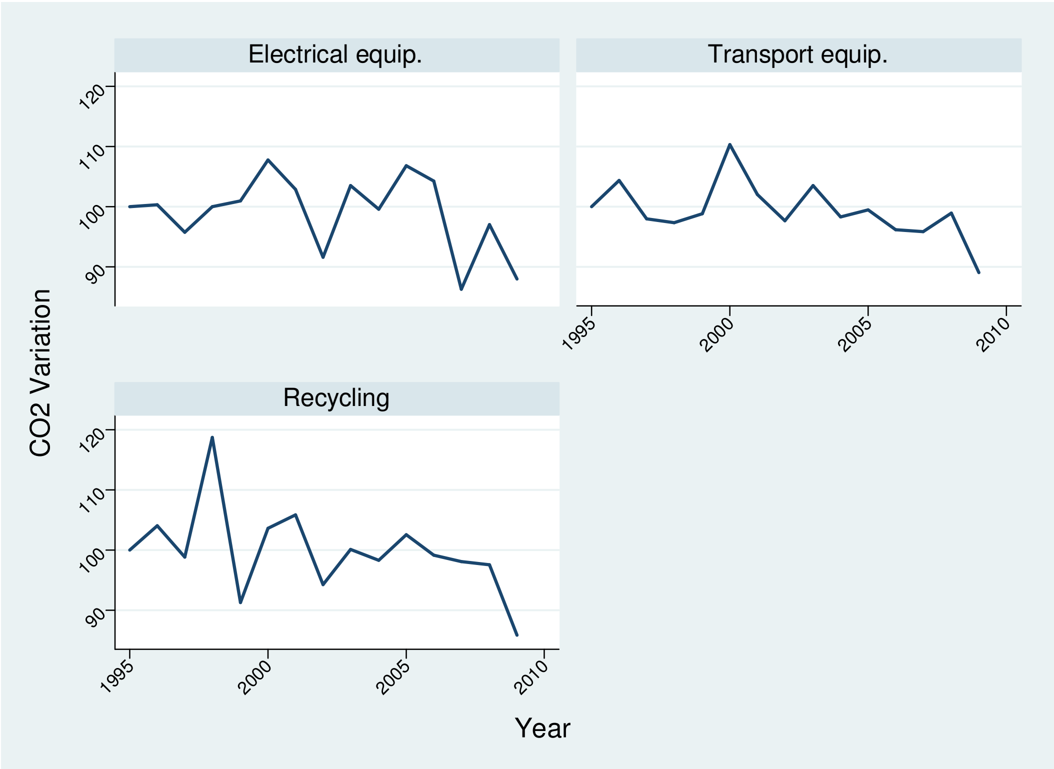

Figure 3. 7 CO2 variation by sector. 1995-2009. (3)

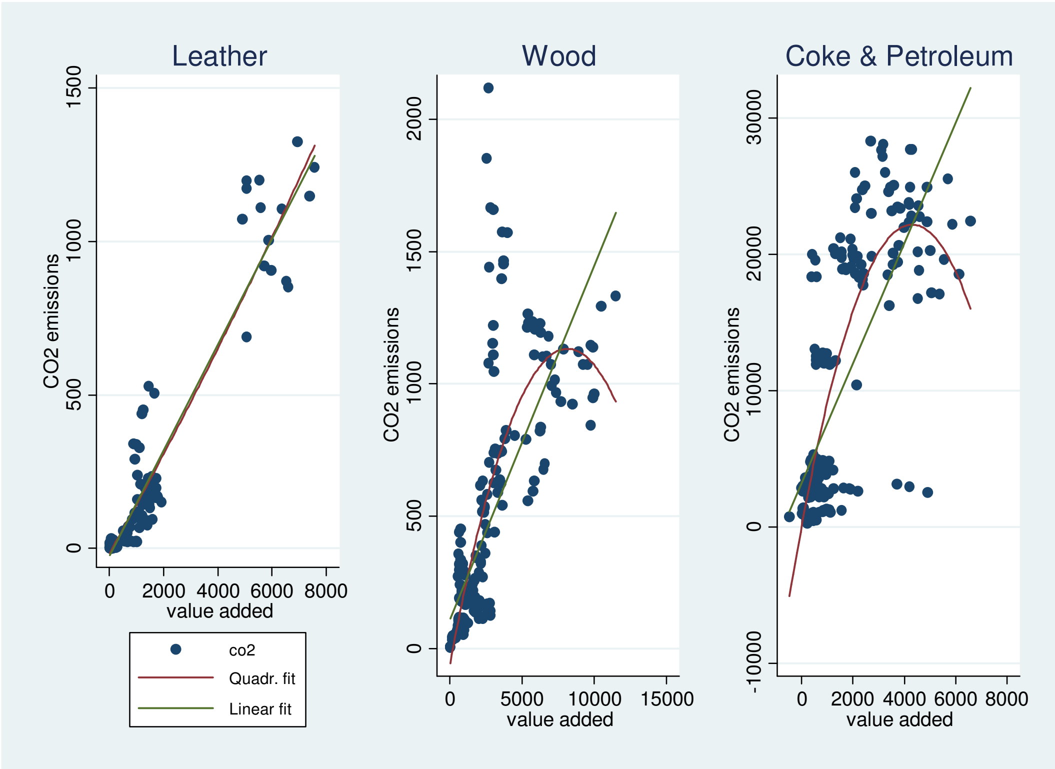

Figure 3. 8 CO2 and Value added scatterplot by sector (1)

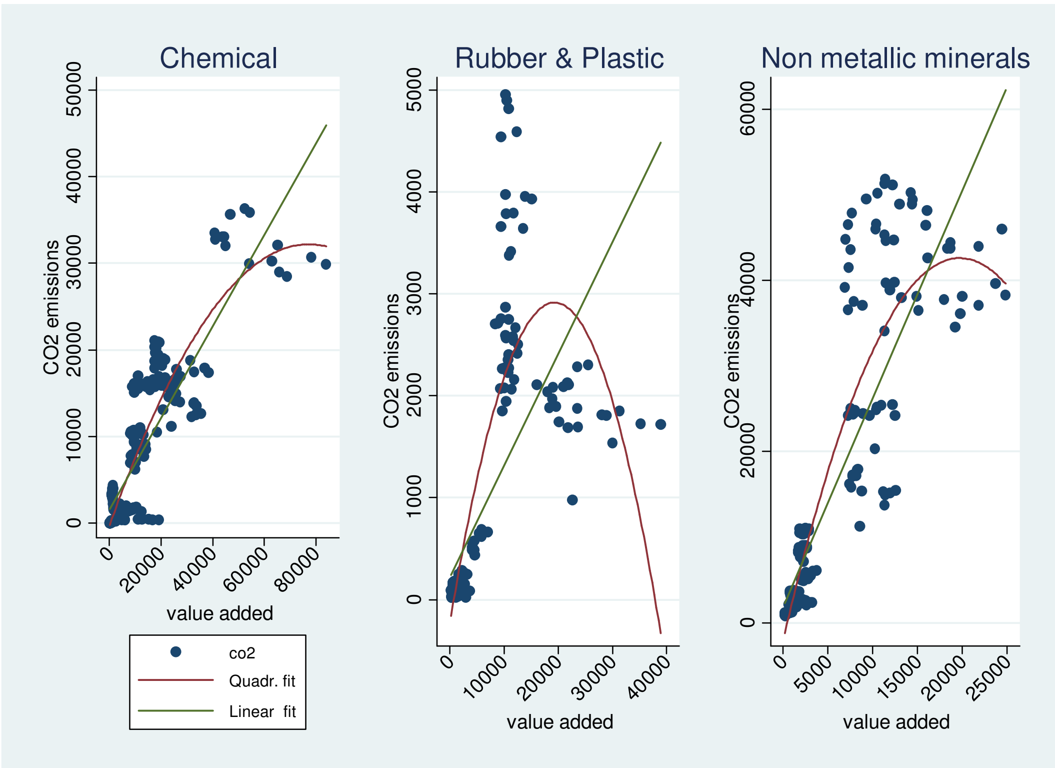

Figure 3. 9 CO2 and Value added scatterplot by sector (2)

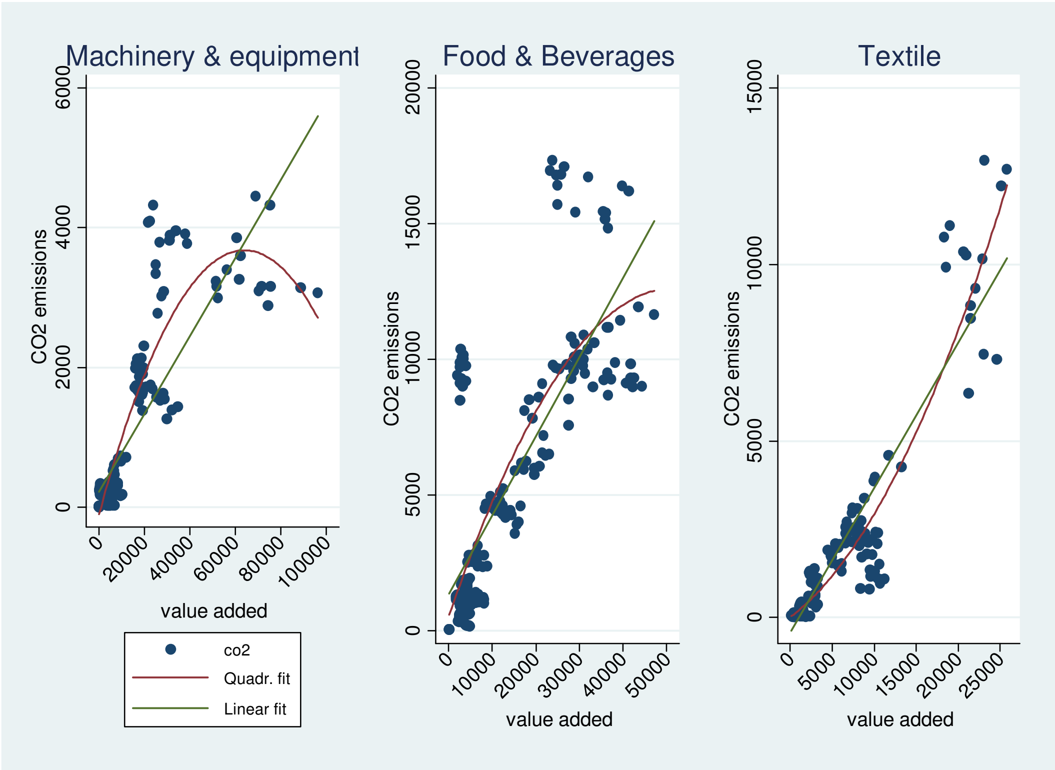

Figure 3. 10 CO2 and Value added scatterplot by sector (3)

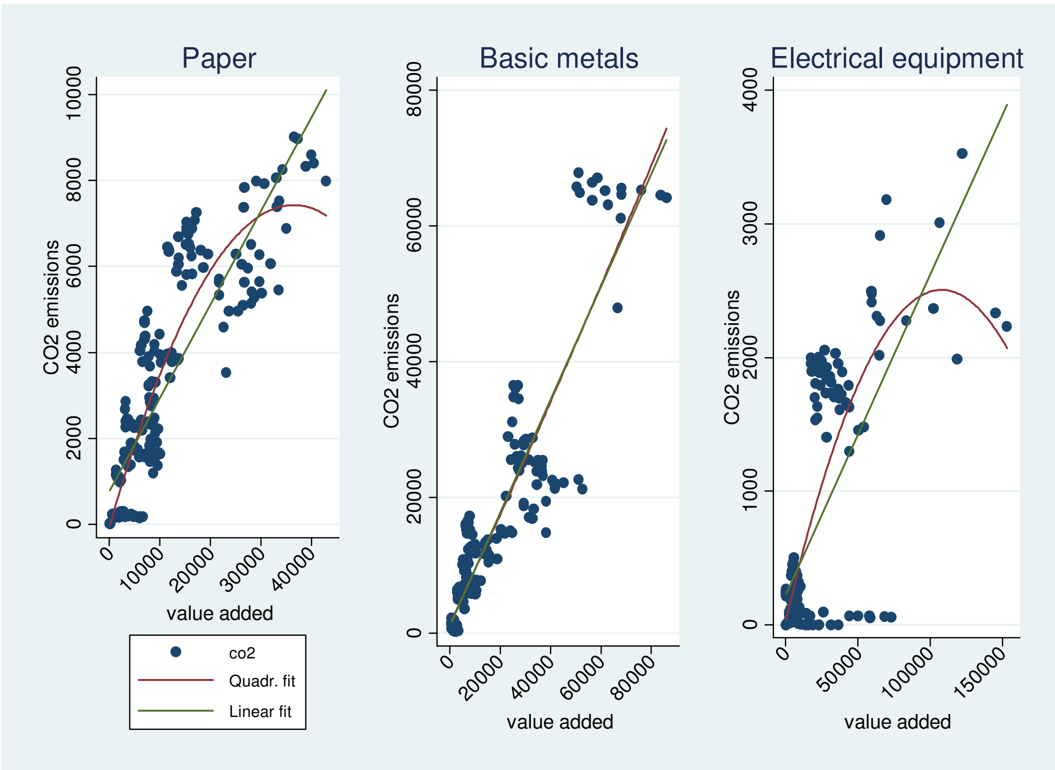

Figure 3. 11 CO2 and Value added scatterplot by sector (4)

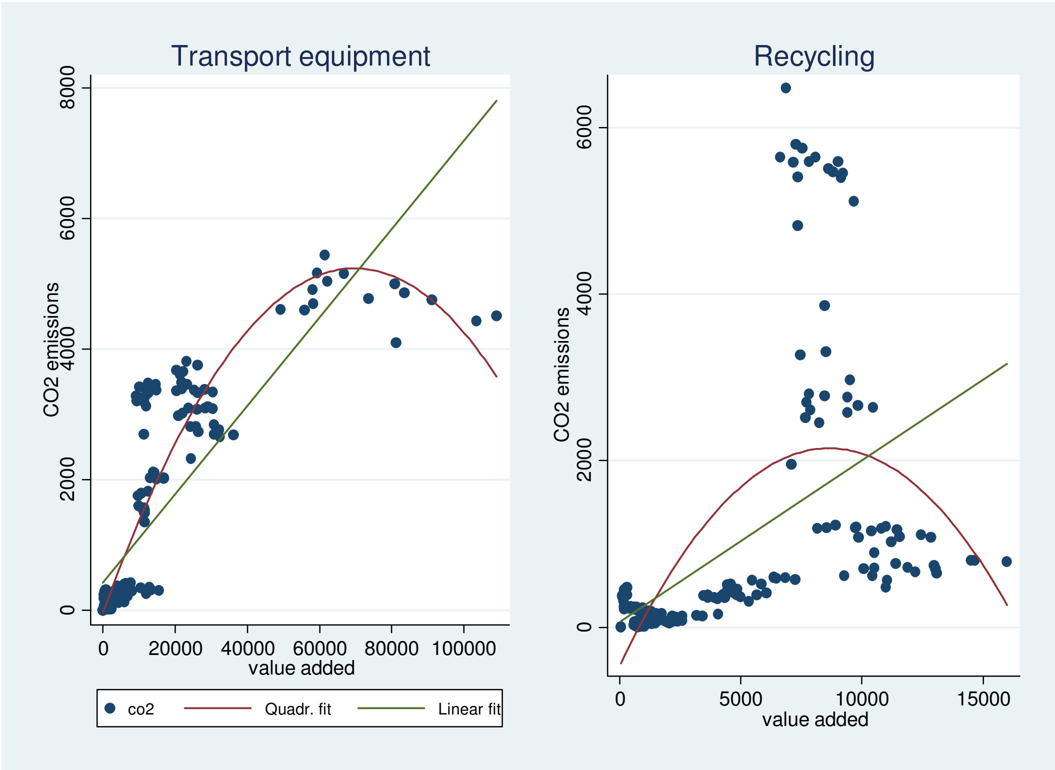

Figure 3. 12 CO2 and Value added scatterplot by sector (5)

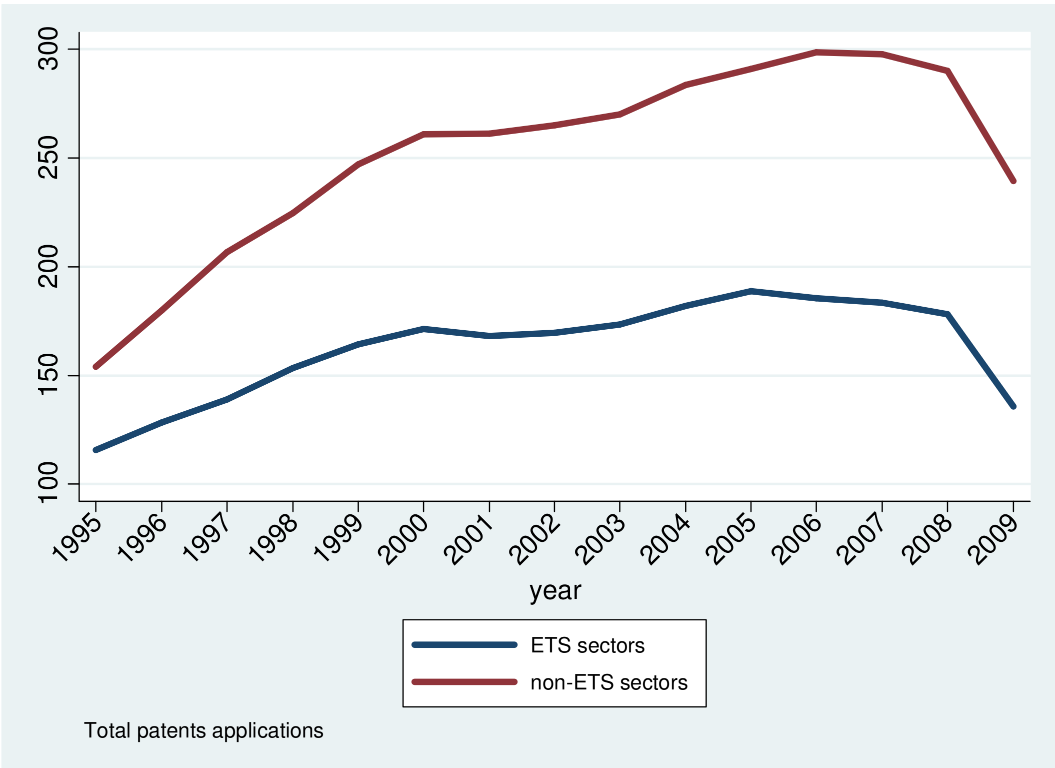

Figure 3. 13 Total patents application in ETS and non-ETS sectors. 1995-2009

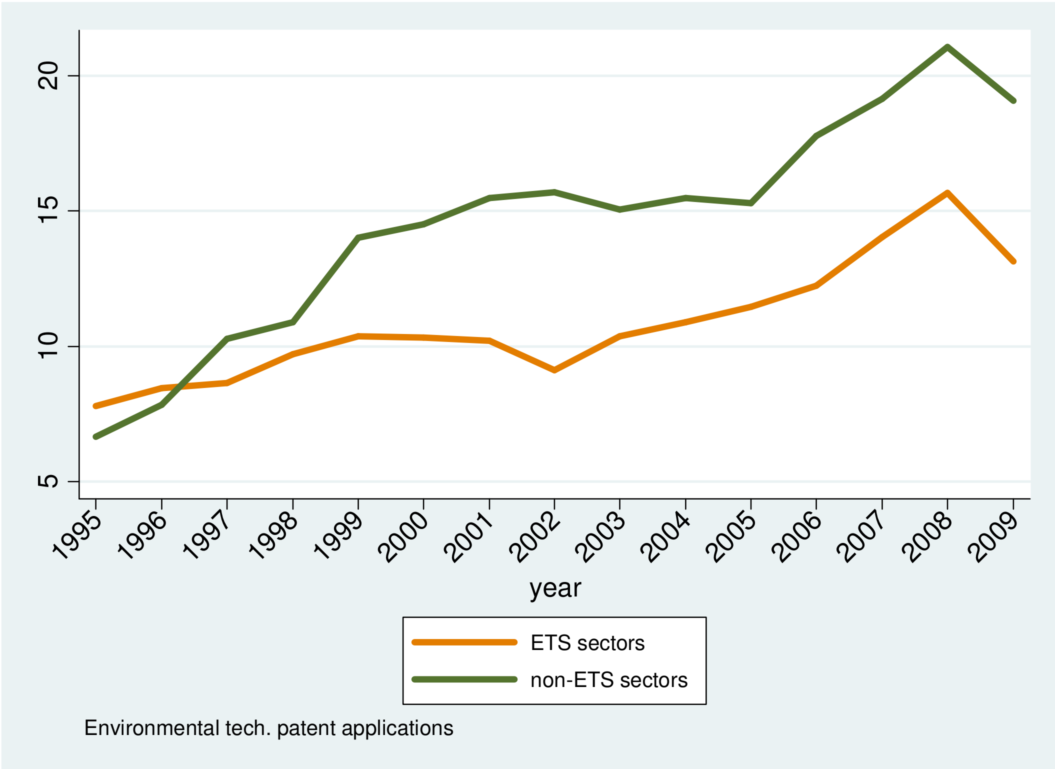

Figure 3. 14 Green patents application in ETS and non-ETS sectors. 1995-2009

Table 3. 4 Policy adoption by category of instrument.

Policy	Deposit-refund scheme	Taxes	Treadable permits	Voluntary approaches	Subsidies	Fees and Cherges
Not present	3014	2558	2773	2859	3039	2982
Present	136	592	375	291	111	168
Total	3150	3150	3148	3150	3150	3150

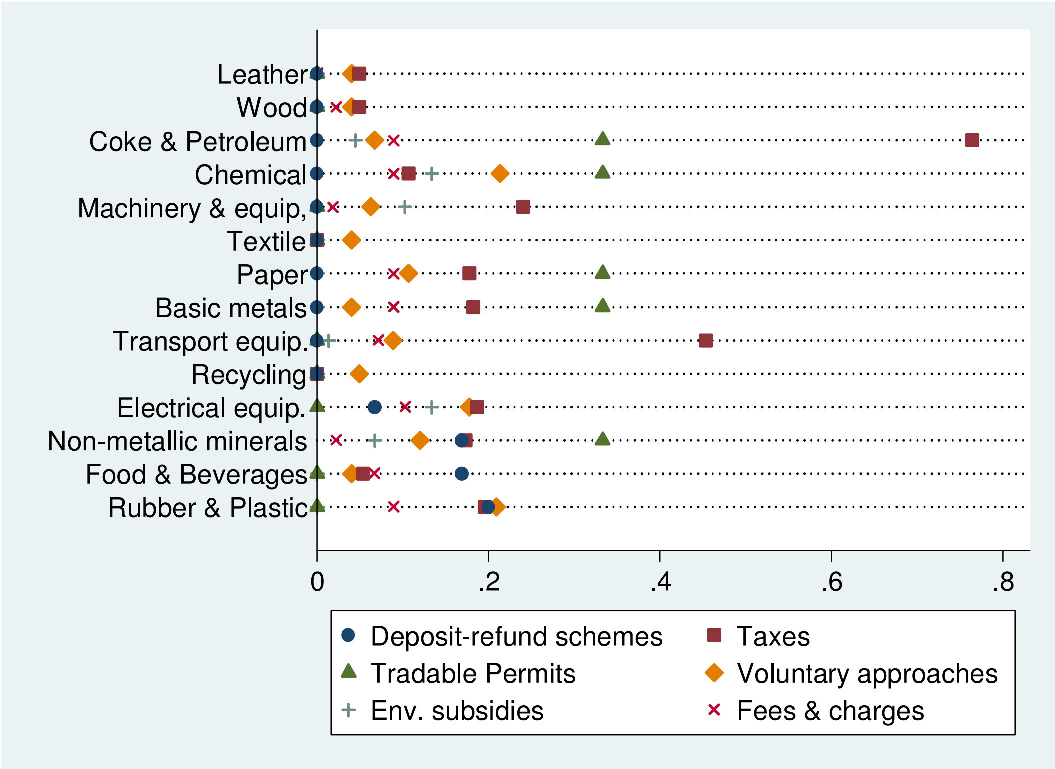

Figure 3. 15 Policy adoption by instrument and sector

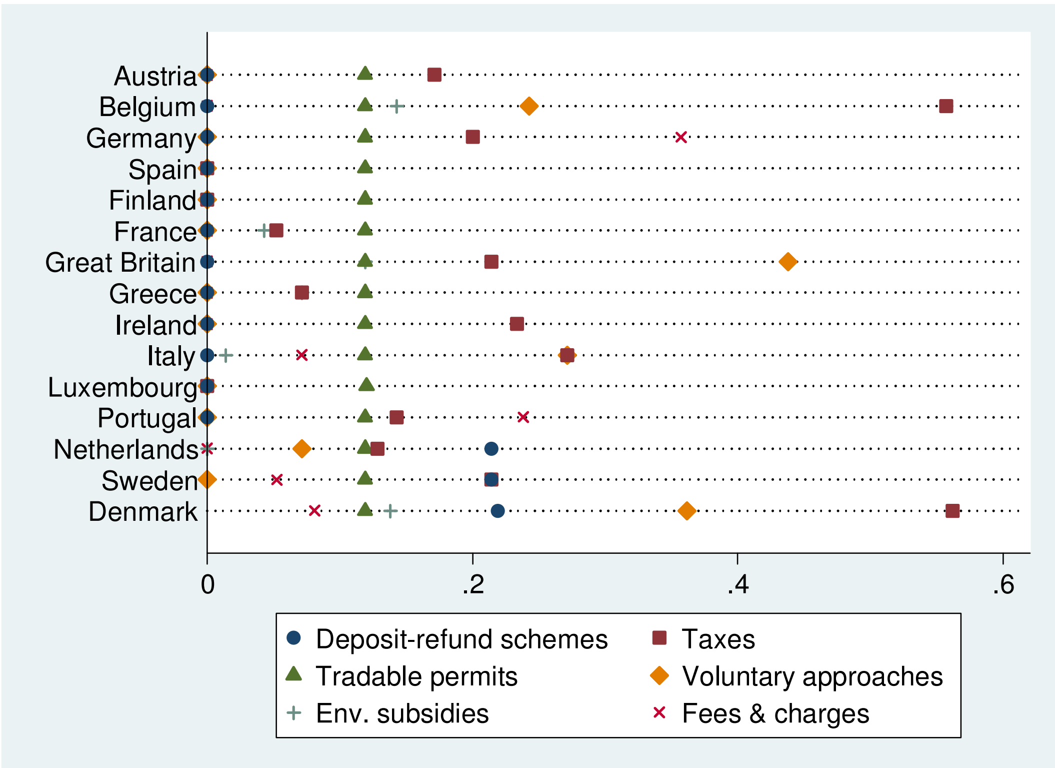

Figure 3. 16 Policy adoption by instrument and country

Table 3. 5 Random effects regression. Total patents used as technological change indicator.

	(1) co2	(2) co2
Lag patent stock	-0.175***	-0.228***
	(0.0615)	(0.0531)
Value Added	0.0339***	0.0420***
	(0.0128)	(0.0142)
Policy Index	-213.2**	-139.8*
	(89.42)	(83.01)
Technology*Policy		-0.188***
		(0.0618)
_cons	4105.1***	4075.9***
	(569.9)	(557.3)
N	2811	2811

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

Table 3. 6 Random effects regression. Green patents used as technological change indicator.

	(1) co2	(2) co2
Green patents stock	-1.879*	-1.316
	(0.977)	(1.079)
Value Added	0.0196*	0.0166
	(0.0106)	(0.0114)
Policy Index	-210.6**	-171.4**
	(88.95)	(85.74)
Green tech*Policy		-1.746*
		(0.907)
_cons	4181.2***	4199.9***
	(581.8)	(578.9)
N	2811	2811

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

Table 3. 7 Fixed effect regression results including time and sectorial interaction (left column) and individual trend (right column). Total patents used as technological change indicator

	Year*NACE	Trend
	co2	co2
Lag patent stock	-0.215***	-0.214***
	(0.048)	(0.049)
Value added	0.032***	0.034***
	(0.012)	(0.012)
Policy index	-64.536	-180.4**
	(83.448)	(83.02)
Technonolgy*Policy	-0.175***	-0.186***
	(0.057)	(0.062)
_cons	4224.663***	4076.7***
	(127.744)	(99.33)
Year FE	Yes	No
NACE FE	Yes	No
Individual trend	No	Yes
Interaction	Yes	Yes
N	2811	2811

Table 3. 8 Fixed effect regression results including time and sectorial interaction (left column) and individual trend (right column). Green patents used as technological change indicator

	Year*NACE	Trend
	co2	co2
Green patents stock	-1.108	-1.199
	(0.955)	(1.053)
Value Added	0.010	0.010
	(0. 009)	(0.010)
Policy Index	-78.464	-211.6**
	(84.399)	(86.32)
Green tech*Policy	-1.564*	-1.735*
	(0. .810)	(0.900)
_cons	4382.4***	4202.6***
	(110.411)	(83.17)
Year FE	Yes	No
NACE FE	Yes	No
Individual trend	No	Yes
Interaction	Yes	Yes
N	2811	2811

Conclusion

The last three decades have been marked by increasing efforts of policy makers in addressing environmental issues and other concerns related to climate change. Innovation assumed a central role in this context, since it is considered the mean through which both firms' competitiveness and environment can be preserved, thus promoting the achievement of an optimal social outcome. Because of the increasing attention to innovation and especially to environmental innovation, researchers have focused on the drivers and on other factors that can enhance their adoption and diffusion.

Unfortunately, beside the thriving literature on the determinants of eco innovation and its economic effects, there is a lack of contributions on its actual environmental impacts. The few contributions summarized in the introduction, allowed to identify three mechanism through which innovation affects environmental performances. First innovation may cause inflation of other relevant economic variables (e.g. labour productivity); second, effects of innovations might be driven by administrative and geographical factors; third, there exist inter-firms effects which may cause a decline in the overall emissions of a sector.

The purpose of this dissertation is to contribute to the existing literature on the effects of innovation on the environment. An element of novelty with respect to the existing literature is the inclusion of the European countries, which goes beyond the country perspective and considers the differences among cultural and institutional features in improving environmental performance, under the guise of the European directives. Coherently, throughout the whole dissertation, the analysis is carried at the sector level, which following a seminal paper by Dopfer (2012) is the most appropriate level of analysis to investigate innovation's adoption and diffusion. An original feature lies in the different perspective under which this issue is addressed: first, by investigating the actual conditions of the economic, environmental and innovation performances in five main EU countries selected for their diverse economic and institutional backgrounds; secondly, by considering the interaction between different typologies of innovations and finally by analyzing the evolution of innovation and polluting emissions through time and innovation interactions with policy.

Chapter 1 provided a descriptive analysis of the joint economic, innovative and environmental performances of five main European countries, namely Italy, Sweden, Germany, France, Finland, which have been selected because of their different economic and institutional features. Their changing economic structure have been analyzed in the light of their innovative and environmental performances and both in static and dynamic terms. Environmental performances indicators considered were CO2 emission intensity, SOx emission intensity and energy use intensity; economics indicators included were value added and labour productivity; finally, innovation indicators were innovation directed to CO2 emissions abatement, innovation for the improvement of energy efficiency and innovation for waste reduction. Static analysis aimed to describe the economic, environmental and innovative performances in the leading sectors of the economies in 2007, while the dynamic analysis aimed to detect the countries' changing economic specialization together with the evaluation of the outcomes of these sectors. The analysis highlighted a leading role of northern European countries, especially of Germany in both innovation adoption and improvement of environmental performances, while southern countries such as Italy are still lying behind. Moreover, it emerged that even though the industrial structure of countries is shifting form a manufacturing-based economy to a services-based economy, in northern countries such as Germany and Sweden, manufacturing is still important and it is expanding in terms of value added (in particular, the Machinery and Equipment sector in both Germany and Sweden as well as the petroleum and coke sector in the latter).

The aim of Chapter 2 was to investigate the possible effects of the interactions among different typologies of innovation on environmental performances, measured as environmental productivity. Pairs of interactions between environmental innovation and one of the other innovation practices (organizational innovation, process innovation and product innovation respectively) were observed across the European countries at three different level of analysis: the economy as a whole; the manufacturing sector; the sectors covered by the EU-ETS policy. Finally, to control for the existence of differentials in environmental performances and innovation adoption across Europe, two subsamples of northern and southern European countries are included in the analysis. The environmental productivity index was computed as the ratio between value added and CO2 emissions, in line with the seminal paper by Repetto (1990) in year 2009 and in year 2010. Interactions were measured employing the definition of complementarity by Topkis (1998), as applied by Mohnen & Röller (2005): complementarity arises when the joint introduction of two innovation practices improve environmental productivity more than the introduction of just one of the two innovation practices; in this case, the function is said to be supermodular in the outcome, namely that the joint implementation of the two innovation is more convenient. Results have shown that for the European economy, complementarity is not yet an asset that firms are able to exploit to reduce their environmental impacts and this result holds when the analysis is restricted to either the manufacturing or the ETS sectors. However, when considering the subsamples of northern and southern European countries, evidence is found that complementarity arises in the manufacturing sector of northern European countries. This confirms again the superior environmental performance in northern countries in terms of innovation and environmental outcomes, as described also in Chapter 1.

Finally, Chapter 3 is primarily focused on the relation between CO2 emissions and technological change, taking into consideration relevant factors that can be pivotal in reducing carbon emission, namely economic growth (measured with GDP) and policies, which are included in the analysis through the construction of a standardized index enveloping six different policy measures (deposit-refund schemes; taxes; tradable permits; voluntary approaches; environmental subsidies). In addition, the hypothesis of a significant interaction between policies and technological change in achieving a reduction of CO2 emissions is tested. I used patents applications to the EPO to construct the two innovation indicators, namely innovations in all technology fields and innovation in green technology fields only. Results highlighted that even though both total innovation and green innovation have a significant role in reducing CO2 emissions, the significance is greater for total innovation than for green innovation. This can appear counterintuitive, but the total patent indicator collects mainly process innovations while, by construction, green innovation is more related to environmental sustainable products. Because CO2 emissions abatement is more sensible to improvements in the productive processes, the green patent indicator tends to underestimate the impact on green innovation on CO2 level. Concerning the effects of policy, the indicator is not always significant; however, its interaction with both total and green technology always is; this means that the introduction of an environmental policy increases the effects of technological change and therefore these two factors can be defined as complements.

Using different points of view, this dissertation aimed to shed light on the environmental effect of innovation. The focus on the majority of the European countries, constitutes an element of novelty with respect to the existing literature and allows observing results of the European efforts toward a more sustainable economic growth. I believe that this dissertation stressed three main facts: first, European countries are characterized not only by different economic and institutional conditions but also by very diverse environmental performances and innovative efforts. It emerged from Chapters 1 and 2 that the north-European context is characterized by a higher innovation adoption rate, with respect to the EU average as well as by generally better environmental performances. Moreover, these countries are able to exploit better the synergies between different kinds of innovation to improve further their environmental performances. Therefore, a "two-speed Europe" characteristic holds also in terms of innovative and environmental performance. Conversely and in the second place, it emerged a difficulty of the other European countries, particularly in southern Europe, to catch up with the north of Europe both in terms of environmental and innovative performances. This also reflects in a poor economic performance of these countries, as for example in the case of Italy. Finally, adoption of innovation reveals to be successful in improving the reduction of environmental impacts, especially CO_2 emissions. This result might be a positive sign of the right direction of the European Union efforts toward a more sustainable growth and development, particularly if one considers the relevant role of the interactions between policy and technological change.

The extensions of this dissertation can move in different directions: first, the analysis in Chapter 1 may be enriched with an analysis of convergence in emission intensity in Europe, to understand if there exist a process of catching up in terms of environmental performance among the European countries. An extension of Chapter 2 might be to focus on the firm level[48] to investigate the effects of innovation on environmental productivity, to gain some insight on the emissions reduction strategies implemented. Finally the estimation of a dynamic panel data model would further develop Chapter 3, because it would take in account persistence in CO_2 emissions; moreover, it would be useful to find instrumental variables to remove simultaneity between policy and CO_2 emissions.

[48] Microdata of the sixth CIS are available for the implementation of this analysis.

References

Abbott, B.F.M., 2009. *Innovation and Technology Transfer to Address Climate Change : Lessons from the Global Debate on Intellectual Property and Public Health*,

Ambec, S. et al., 2013. The porter hypothesis at 20: Can environmental regulation enhance innovation and competitiveness? *Review of Environmental Economics and Policy*, 7, pp. 2–22.

Andersson, F.N.G. & Karpestam, P., 2013. CO2 emissions and economic activity: Short- and long-run economic determinants of scale, energy intensity and carbon intensity. *Energy Policy*, 61, pp.1285–1294.

Antonioli, D., Mancinelli, S. & Mazzanti, M., 2013. Is environmental innovation embedded within high-performance organisational changes? The role of human resource management and complementarity in green business strategies. *Research Policy*, 42(4), pp.975–988.

Barro, R.J. & Sala-i-Martin, X., 2003. *Economic Growht, 2nd Edition*, MIT press.

Bocquet, R., Brossard, O. & Sabatier, M., 2007. Complementarities in organizational design and the diffusion of information technologies: An empirical analysis. *Research Policy*, 36, pp.367–386.

Borghesi, S., Cainelli, G. & Mazzanti, M., 2012. European Emission Trading Scheme and Environmental Innovation: An Empirical Analysis using CIS data for Italy. *Giornale degli Economisti e Annali di Economia*, 71(October), pp.71–97.

Brunnermeier, S.B. & Cohen, M. a, 2003. Determinants of environmental innovation in US manufacturing industries. *Journal of Environmental Economics and Management*, 45(2), pp.278–293.

Cainelli, G. & Mazzanti, M., 2013. Environmental innovations in services: Manufacturing–services integration and policy transmissions. *Research Policy*, 42(9), pp.1595–1604.

Calel, R. & Dechezlepretre, A., 2012.Environmental Policy and directed technological change: evidences from the European carbon market. *Review of Economics and Statistics.*

Cameron, A.C. & Trivedi, P.K., 2005. *Microeconometrics - Methods and Application*,

Carrión-Flores, C.E. & Innes, R., 2010. Environmental innovation and environmental performance. *Journal of Environmental Economics and Management*, 59(1), pp.27–42.

Carson, R.T., 2009. The environmental Kuznets curve: Seeking empirical regularity and theoretical structure. *Review of Environmental Economics and Policy*, 4, pp.3–23.

Cole, M. a., Elliott, R.J.R. & Strobl, E., 2008. The environmental performance of firms: The role of foreign ownership, training, and experience. *Ecological Economics*, 65(3), pp.538–546.

Corradini, M. et al., 2014. Unveiling the dynamic relation between R&D and emission abatement. *Ecological Economics*, 102, pp.48–59.

Costantini, V. & Crespi, F., 2008. Environmental regulation and the export dynamics of energy technologies. *Ecological Economics*, 66, pp.447–460.

Costantini, V. & Mazzanti, M., 2012. On the green and innovative side of trade competitiveness? The impact of environmental policies and innovation on EU exports. *Research Policy*, 41(1), pp.132–153.

Costantini, V., Mazzanti, M. & Montini, A., 2013. Environmental performance, innovation and spillovers. Evidence from a regional NAMEA. *Ecological Economics*, 89, pp.101–114.

Costantini, V., Mazzanti, M. & Montini, A., 2011. *Hybrid Economic Environmental Accounts*, London: Routledge.

Cozzarin, B.P. & Percival, J.C., 2006. Complementarities between organisational strategies and innovation. *Economics of Innovation and New Technology*, 15, pp.195–217.

Dinda, S., 2004. Environmental Kuznets Curve Hypothesis: A Survey. *Ecological Economics*, 49(4), pp.431–455.

Dopfer, K., 2012. The Origins of Meso Economics. *Journal of Evolutionary Economics*, (22), pp.133–160.

Dosi, G. et al., 2006. Information, appropriability, and the generation of innovative knowledge four decades after Arrow and Nelson: An introduction. *Industrial and Corporate Change*, 15, pp.891–901.

Downing, P.B. & White, L.J., 1986. Innovation in pollution control. *Journal of Environmental Economics and Management*, 13(1), pp.18–29.

Duarte, R., Mainar, A. & Sánchez-Chóliz, J., 2013. The role of consumption patterns, demand and technological factors on the recent evolution of CO2 emissions in a group of advanced economies. *Ecological Economics*, 96, pp.1–13.

Dunn, E.S., 1960. A statistical and analytical technique for regional analysis. *Papers and Proceedings of the Regional Science Association*, (6), pp.97–112.

EEA, 2013. *Towards the green economy*, Cophenhagen.

Esteban, J., 2000. Regional convergence in Europe and the industry mix: a shift-share analysis. *Regional Science and Urban Economics*, 3(30), pp.354–364.

Filippetti, A. & Archibugi, D., 2011. Innovation in times of crisis: National Systems of Innovation, structure, and demand. *Research Policy*, 40(2), pp.179–192.

Garcia-Milà, T. & McGuire, T., 1993. Industrial mix as a factor in the growth and variability of states' economies. *Regional Science and Urban Economics*, 6(23), pp.731–748.

Ghisetti, C. & Quatraro, F., 2013. Beyond inducement in climate change: Does environmental performance spur environmental technologies? A regional analysis of cross-sectoral differences. *Ecological Economics*, 96, pp.99–113.

Gomez, J. & Vargas, P., 2009. The effect of financial constraints, absorptive capacity and complementarities on the adoption of multiple process technologies. *Research Policy*, 38, pp.106–119.

Griliches, Z., 1998. Patent Statistics as Economic Indicators : A Survey. In Z. Griliches, ed. *R&D and Productivity: The Econometric Evidence*. University of Chicago Press, pp. 287–343.

Hall, B.H., Lotti, F. & Mairesse, J., 2012. Evidence on the impact of R&D and ICT investments on innovation and productivity in Italian firms. *Economics of Innovation and New Technology*, pp.1–29.

Horbach, J., 2008. Determinants of Environmental Innovations, New Evidence From German Panel Data Source. *Research Policy*, 1(37), pp.163–73.

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

Jaffe, A.B., Newell, R.G. & Stavins, R.N., 2002. Environmental Policy and Technological Change. *Environmental and Resource Economics*, (22), pp.41–69.

Jaffe, A.B. & Palmer, K., 1997. Environmental Regulation and Innovation: A Panel Data Study. *Review of Economics and Statistics*, 79(4), pp.610–619.

Kemp, R., 2000. Technology and Environmental Policy - Innovation effects of past policies and suggestions for improvement in Innovation and Environment, OECD, Paris.

Kemp, R. & Pearson, P., 2007. *Final report MEI project about measuring eco- innovation*, UNU-MERIT.

Kemp, R. & Pontoglio, S., 2011. The innovation effects of environmental policy instruments — A typical case of the blind men and the elephant? *Ecological Economics*, 72, pp.28–36.

Lanoie, P., Patry, M. & Lajeunesse, R., 2008. Environmental regulation and productivity: New findings on the Porter Hypothesis. *Journal of Productivity Analysis*, 30, pp.121–128.

Lanzi, E., 2013. *Encyclopedia of Energy, Natural Resource, and Environmental Economics* 1st ed., Elsevier.

Leeuwen, G. Van & Mohnen, P., 2013. Revising the Porter Hypothesis: An empirical analysis of green innovation for Netherlands, UNU-MERIT *Working Paper Series*, 2013-002.

Malerba, F., 2004. An Interpretation of the Stylized Facts Structural Change in Innovative Activities in Four Leading Sectors An Interpretation of the Stylized Facts, *Presses de Science Po*, (55), 2004/06

Malerba, F., 2002. Sectoral systems of innovation and production. *Research Policy*, 31, pp.247–264.

Malerba, F., Orsenigo, L. & Breschi, S., 2000. Technological regimes and schumpeterian patterns of innovation. *The Economic Journal*, 110, pp.388–410.

Mancinelli, S. & Mazzanti, M., 2009. Innovation, networking and complementarity: Evidence on SME performances for a local economic system in North-Eastern Italy. *Annals of Regional Science*, 43, pp.567–597.

De Marchi, V., 2012. Environmental innovation and R&D cooperation: Empirical evidence from Spanish manufacturing firms. *Research Policy*, 41, pp.614–623.

Marin, G. & Mazzanti, M., 2010. The evolution of environmental and labor productivity dynamics. *Journal of Evolutionary Economics*, 23(2), pp.357–399.

Marin, G., Mazzanti, M. & Montini, A., 2012. Linking NAMEA and Input output for "consumption vs. production perspective" analyses. Evidence on emission efficiency and aggregation biases using the Italian and Spanish environmental accounts. *Ecological Economics*, 74, pp.71–84.

Mazzanti, M. & Montini, A., 2009. Regional and Sector Environmental Efficiency Empirical Evidence from Structural Shift-share Analysis of NAMEA data, Working Paper n. 2009.11. FEEM, Venice.

Mazzanti, M. & Montini, A., 2010. Embedding the drivers of emission efficiency at regional level — Analyses of NAMEA data. *Ecological Economics*, 69(12), pp.2457–2467.

Mazzanti, M. & Musolesi, A., 2013. The heterogeneity of carbon Kuznets curves for advanced countries: comparing homogeneous, heterogeneous and shrinkage/Bayesian estimators. *Applied Economics*, 45, pp.3827–3842.

Mazzanti, M. & Zoboli, R., 2009. Environmental efficiency and labour productivity: Trade-off or joint dynamics? A theoretical investigation and empirical evidence from Italy using NAMEA. *Ecological Economics*, 68(4), pp.1182–1194.

Milgrom, P. & Roberts, J., 1995. Complementarities and fit strategy, structure, and organizational change in manufacturing. *Journal of Accounting and Economics*, 19, pp.179–208.

Milgrom, P. & Roberts, J., 1990. The Economics of Modern Manufacturing: Technology, Strategy, and Organization. *The American Economic Review*, 80, pp.511–528.

Mohnen, P. & Röller, L.-H., 2005. Complementarities in innovation policy. *European Economic Review*, 49(6), pp.1431–1450.

Nesta, L., Vona, F. & Nicolli, F., 2014. Environmental policies, competition and innovation in renewable energy. *Journal of Environmental Economics and Management*, 67(3), pp.396–411.

Popp, D., Hascic, I. & Medhi, N., 2011. Technology and the diffusion of renewable energy. *Energy Economics*, 33(4), pp.648–662.

Popp, D., Newell, R.G. & Jaffe, A.B., 2009. Energy, the Environment and Technological Change,Working Paper n. 14832, *NBER Working Paper Series*.

Porter, M.E. & Linde, C. Van Der, 1995. Toward a New Conception of the Environment-Competitiveness Relationship. *American Economic Association*, 9(4), pp.97–118.

Repetto, R., 1990. Environmental Productivity and why it is so important. *Challenge*, 33(5), pp.33–38.

Roberts, J., 2006. *The Modern Firm. Organizational Design for Performance and Growth*, Oxford: Oxford University Press.

Rogge, K.S. & Hoffmann, V.H., 2010. The impact of the EU ETS on the sectoral innovation system for power generation technologies – Findings for Germany. *Energy Policy*, 38(12), pp.7639–7652.

Rogge, K.S. & Hoffmann, V.H., 2009. The Impact of the EU ETS on the Sectoral Innovation Systems for Power Generation Technologies - Findings for Germany. *Energy Policy*, 38, pp.7639–7652.

Schmiedeberg, C., 2008. Complementarities of innovation activities: An empirical analysis of the German manufacturing sector. *Research Policy*, 37, pp.1492–1503.

Timmer, M.P., 2012. The World Input-Output Database (WIOD): Contents , Sources and Methods, Working Paper n. 10, *WIOD working Paper Series.*

Topkis, D.M., 1978. Minimizing a Submodular Function on a Lattice. *Operations Research*, 26, pp.305–321.

Topkis, D.M., 1998. *Supermodularity and Complementarity*, Princeton, NJ: Princeton University Press.

United Nations, 1998. Kyoto Protocol to the Uninted Nations, Kyoto.

Verbeek, M., 2012. *A Guide to Modern Econometrics 4th edition*, Wiley.

Veugelers, R., 2012. Which policy instruments to induce clean innovating? *Research Policy*, 41, pp.1770–1778.

Wang, Z. et al., 2012. Energy technology patents–CO2 emissions nexus: An empirical analysis from China. *Energy Policy*, 42, pp.248–260.

York, R., Rosa, E.A. & Dietz, T., 2003. STIRPAT, IPAT and ImPACT: Analytic tools for unpacking the driving forces of environmental impacts. *Ecological Economics*, 46, pp.351–365.