Chapter 1

Macroeconomic Determinants of Environmental Innovations in Europe: A Panel Approach

1.1 Introduction

An environmental public awareness has emerged these last decades as a result of major technological accidents, ecological disasters and environmental damages caused by the daily human activities and wastes. Therefore, lessening the environmental impact of economic and human activities while maintaining the economic growth has become the major challenge of the 21st century. To realize this objective, policymakers and scholarships try to give substances to the concept of green economic growth and sustainable development by clearly defining the means to achieve them. Within this framework, environmental innovation economy is regarded as one of the key elements to ensure the transition to green economy [1]. Public authorities have a fundamental role to promote them by developing social structures, implementing financial schemes, supporting programs for green R&D, fostering eco-markets and introducing environmental regulations (Jang et al. (2015)).

It is in this context that studies on the determinants of eco-innovation exploded in recent years. Academic research, done so far, mostly focused on micro and meso-economics levels. The authors wanted to find out what factors push companies or industries to eco-innovate. It is important to have this kind of studies to go deeper in details at different levels(micro, meso, regional, technological, specific clusters) (Miettinen, 2002). However, if we want to build a comprehensive and coherent project and "[a]*s long as nation states exist as political*

[1] The terms "environmental innovation" and "eco-innovation" are used interchangeably throughout this article even though some researchers differentiate them by considering the eco-innovation as an environmental innovation that improve simultaneously environmental and economic performances (Ekins, 2010).

entities with their own agendas related to innovation, it is useful to work with national systems as analytical objects" (Lundvall et al., 2002, p 215). This is particularly true for eco-innovation which necessitates in addition a coordination between countries due to the nature of the environmental problems that are global and have absolute limits and possible solutions only at a global level.

So the aim of this article is to identify the determinants of eco-innovation at macro-level in European countries. Because of their sensitivity to the environmental concerns, these latter represent an interesting analytical framework. They were the first to put quantitative objectives in their European environmental policy agenda i.e. a 20% reduction in greenhouse gas emissions, with a 20% share of renewable energy source used in final energy consumption, and a 20% reduction of final energy consumption for the year 2020 compared to 1990 levels. They fixed new objectives of a 40% reduction in greenhouse gas emissions for 2030 and longer term targets to decarbonize the European energy system and cut EU's greenhouse gas emissions by 80 to 95% by 2050. They also implemented the European Trading Scheme, established under the Directive 2003/87/EC, which is the largest available cap-and-trade system in the world and considered as the cornerstone of EU's strategy for addressing climate change.

This chapter identifies in the first step, theoretically macroeconomic determinants of eco-innovations. It connects on the one hand, the findings of the environmental and innovation economics and on the other hand, the findings of the endogenous growth theory and the National Innovation System approach. The two first fields focus on micro determinants. The environmental economics stresses the fundamental role of the environmental regulations to boost eco-innovations while the innovation economics added technology-push and demand-pull drivers. These last categories of drivers are studied at aggregate level by the endogenous growth theory. Meanwhile, National Innovation System approach focuses on the role of national institutions. In the second step of the chapter, inspired by the empirical works evoked in the previous part, the study analyses the drivers of eco-innovation by evaluating different variables belonging to the categories cited above (technology-push, demand-pull and institutions with a special focus on regulation) using a panel approach for 12 European countries over the period 1990-2012.

The remainder of the paper is organized as follows. Next section reviews the existing literature and provides an overview of empirical works dealing with this issue. Section 3 introduces the model and the dataset employed. Empirical analysis and result discussions are presented in section 4. Section 5 concludes.

1.2 Literature review

In order to understand the determinants of eco-innovations at the macroeconomic level, this paper mobilizes different streams of research with two study objects. The first group of streams addresses the determinants at the micro (firms) and meso (industrial) levels. Meanwhile, the second has the macroeconomic determinants of innovation in general as a study object.

1.2.1 The micro eco-Innovations' determinants

From a conceptual point of view, this section matches together the environmental and the innovation economics.

Environmental economics

Traditionally the majority of theoretical and empirical works in Environmental economics focus on the role of policy instruments to induce eco-innovation. The term "induced innovation" is inherited from Hicks'work (1932), which states that changes in the relative prices of production factors, such as labour or capital, stimulate the development and diffusion of new technologies in order to save the use of these factors. So the environmental economics highlights the environmental externality generated by the agents' activities (Pigou, 1920) and postulates the existence of an "optimal level of pollution". Regulation is considered, implicitly, as the sole instrument to reach this optimal level by making environmental goods costly whereas previously they were considered to be abundant and cheap goods. Subject to these public policy interventions, manufacturers must make a trade-off between economic gains and environmental benefits when adopting eco-innovations.

Porter (1991) and Porter and van der Linde (1995, 1999) challenge the assumption of "trade-off" and argue that strict but flexible environmental regulations not only promote the environmental performance of companies, but also can improve their economic performance. The regulation must no longer be seen as an additional burden on businesses but as an effective way to address market failures. From an empirical point of view, three versions of the Porter Hypothesis have been tested: the 'weak', the 'strong' and the 'narrow' version (Jaffe and Palmer, 1997). The first one takes up the idea that environmental regulations induce eco-innovations but that their opportunity cost is greater than the net profit obtained. The 'strong' version, is the dynamic one and claims that environmental regulations can foster competitiveness and productivity but in a medium/long term. The last version argues that only flexible environmental regulations, notably market-based ones, can improve competitiveness through the induced innovation.

The huge amount of literature developed in this area is far from being homogenous whether in term of methodology or results. Table 6 summarizes results of some empirical articles[2]. These latter are classified according to the version of the hypothesis tested (weak VS strong and narrow version) and in each category they are classified according to the level of analysis. As shown in the table, the majority of earlier studies is driven at firm and industry level and mainly uses "pollution abatement cost expenditures" (PACE) as a proxy of the environmental regulation stringency. Nevertheless, several problems have been identified in the literature concerning the use of this measure. The first problem concerns the interpretation of PACE. In fact, the idea behind the use of this proxy is that a higher spending in PACE reflects tighter regulation. However this can be one interpretation among others (Jaffe and Palmer, 1997). Inefficiency of polluting firms can also cause high environmental compliance costs and it cannot in this circumstance be interpreted as stringency. At aggregate level, countries with several polluting industries will also have relatively high expenses in PACE regardless of the stringency of their policies (Levinson, 1999; Brunel and Levinson, 2013). The second problem relates to the impact of PACE on innovations. Even if assuming the positive correlation between PACE and regulation stringency, polluters can devote resources towards pollution abatement rather than eco-innovations. In addition, firms can reduce their environmental effect through decisions that do not require expenditures i.e. outsourcing or offshore agreements (Koźluk and Zipperer, 2015). Thirdly, in a cross-country context, "*such a variable is inappropriate due to the heterogeneity in the definitions used and sampling strategies. For instance, in some countries the expenditures of 'specialized' firms in the environmental goods and services sector are included, while in other countries this is not the case*" (Johnstone et al., 2012, p9). For these reasons other measures have started to be used in recent years like environmental taxes revenues, standards, perceived

[2] Table inspired and completed from Ambec and Lanoie (2007)

stringency but they are imperfect measures of regulatory stringency as well. For example concerning the environmental taxes, the European countries do not have a widespread application of them. The EEA report (2014) confirms that the EU-27 environmental taxes as a percentage of total tax revenues fell from 6.9% in 1999 to 5.9% in 2008 and as a percentage of GDP fell from 2.8% to 2.3%. In addition in Europe, the largest share of European environmental taxes is held by energy ones. Those taxes are not usually introduced to tackle environmental issues. Among other purposes, "[they] *are introduced as a relatively efficient source of tax revenue (due to the inelastic nature of energy demand) or they may act as strategic fiscal tools to improve energy security (relevant for countries with limited natural and mineral resources) or to translate part of the fiscal burden on foreign producers of energy*" (Franco and Marin, 2015, p13). Moreover, the environmental taxes, as the other policy instruments, are usually very context-specific while many scholarships highlight the inducement effect of environmental policy mix on the innovation path and not only the use of a unique instrument (Hemmelskamp, 1997; Leone and Hemmelskamp, 1998; Requate, 2005; Requate and Unold, 2003; Roediger-Schluga, 2004; Goulder and Parry, 2008; Afif and Spaeter, 2009; Afif, 2012; Brouillat and Oltra, 2012; Klewitz et al., 2012; Veugelers, 2012; Williamson and Lynch-Wood, 2012). Due to these drawbacks and since this paper deals with a broadly-defined eco-innovation and hence covers multiple environmental impacts we will use a newly-released environmental policy stringency (EPS) index as it will be explained later.

Finding an adequate measure of innovation is still an unsolved issue despite the progress made in recent decades (Freeman and Soete, 2009; Blind, 2012). Empirical studies proxy innovation, generally, in one of two ways: R&D expenditures and number of (eco-)patent grants. The main shortcoming with the use the R&D expenditures is that it represents the resources devoted to the input of the innovation process rather than the innovation realized (Kemp and Pearson, 2008). In this chapter we use the number of eco-patents even that this measure also has some known weaknesses especially under a deeper understanding of the innovation's notion including non-technological aspects (Blind, 2012). As pointed out by Griliches (1990, p.1669) "*Not all inventions are patentable, not all inventions are patented, and the inventions that are patented differ greatly in "quality", in the magnitude of inventive output associated with them*". Moreover, patents are neither the only nor even the most common form to protect innovations. Cohen et al. (2000) point out the industrial secrecy, marketing strategies and lead times as more widespread strategies. However, the use of patent data has been considered as one of the best technological innovations proxy for many reasons. First, it focuses on outputs of inventive process rather than inputs as it is the case for R&D expenditures (Griliches, 1990; Furman et al., 2002; Johnstone et al., 2012). Second, the majority of economically important inventions have been patented (Van Pottelsberghe et al., 2001). Finally, patent data related to environment are easily available nowadays.

Among the most known studies we find the article of Jaffe and Palmer (1997) which distinguishes theoretically the three types of the Porter hypothesis but tests only the "weak" version, i.e. the relationship between stringency and innovation, due to the data restriction[3]. The authors used a panel data set of U.S. manufacturing industry from 1973 to 1991. The regulation stringency is measured by PACE and the innovation is expressed in two ways, R&D expenditures and patents. The empirical results verify that there is a positive link between PACE and R&D expenditures but the link is insignificant using patents. Hence their suggestion to improve the study by looking for better classification of patents into industries, finding more disaggregated data and using other measure of regulation stringency. Brunnermeier and Cohen (2003) extended the analysis of Jaffe and Palmer (1997) by using, for the first time, the number of environmental patent applications granted instead of all patents as a measure of eco-innovation. They also added monitoring and enforcement activities related to existing policies as a second proxy of stringency. They find that environmental innovation occurs in industries with very competitive international markets and conclude that PACE have positive influence on eco-patents, however, it is not the case of monitoring and enforcement activities that provide no additional incentive. To overpass some of the above mentioned PACE drawbacks, Lanoie et al. (2008) use the changes in the ratio of the value of investment in pollution control equipment to the total cost and add regulation on safety in the workplace index. They find that environmental regulation has a positive impact but only in a medium term (using until three-year lagged regulation) on the productivity of 17 Quebec manufacturing industries and that effect is greater when industries are more exposed to international competition which is in line with the "strong" version of the PH. Another article of Lanoie et al. (2011) tested simultaneously the three versions of the PH using a survey of over 4000 manufacturing facilities in seven OECD countries. It looks to the impact of more stringent regulations on R&D (weak), environmental result (narrow) and

[3]For example, market instruments have not been widely used so far to conduct a direct test of the "narrow" version of PH.

business results (strong). It finds strong support to the weak, positive one to the narrow but no support to the strong version. Focusing on European countries, the works of Rubashkina et al. (2015) and Franco and Marin (2015) test the "weak" and the "strong" versions of PH. Rubashkina and her co-authors (2015) find a positive impact of the PACE on the number of patents (the "weak" version) but find no evidence in favour or against the impact of PACE on productivity (the "strong" version). Franco and Marin (2015) tested the impact of environmental taxes on innovation and productivity not only in one same sector but also in the upstream and downstream sectors in terms of input-output relationship. They find that the strongest effects on the "weak" and "strong" version come from the downstream sectors. They also test the indirect effect of the tax on productivity by using patents as mediators and find no impact of the innovations' proxy on productivity[4].

Recently, few empirical works involve macroeconomic level analysis were conducted[5]. Albrizio et al. (2014) is among the first studies that used EPS index and tested its impact at the three levels: macro, meso and micro. They affirm that, at the macro level, productivity growth undergoes an announcement effect of the policy stringency change but this negative affect is offset three years after. De Santis and Jona-Lasinio (2015) studied a panel of 11 EU countries over the period 1995-2008 and used a multitude of environmental stringency measures. They found that the market based instruments are more likely to positively affect production growth than non-market instruments. In a very recent working-paper, Morales-Lage et al. (2016) test the "weak" and the "strong" versions of the PH using the EPS index and two different econometric models i.e. panel models and quantile regression techniques. They confirm the positive impact of the regulation stringency on innovation and productivity. They then demonstrate that EPS index has a greater impact on the lower quantile of the R&D distribution and on the highest quantiles of patents and total factor productivity distributions.

Innovation economics

Innovation economics awards an important role to regulation as a determinant of eco-innovation as well. According to this literature, regulation can resolve the "double external-

[4]Still focusing on European countries and on supply chains but using a qualitative method, Barsoumian et al. (2011) argue that industries which build narrow networks can benefit from highly integrated supply chains to reduce costs. In such a case, industries remain competitive on a global scale while reducing their energy consumption and carbon footprint.

[5]There is a literature at the macro level, not developed in this work, that focused on the impact of environmental stringency on international trade flows see for example Tobey (1990), Low and Yeats (1992), Van Beers and Van Den Bergh (1997), Xu and Song (2000), De Santis (2012), Sauvage (2014).

ity" problem related to eco-innovation. Indeed, this latter generates two types of positive externalities in both the "*research and innovation*" phase, and the "*adoption and diffusion*" phase. For the first phase the positive externalities are usual and the private underinvestment can be compensated by classical instruments like for example patents. In contrast, the positive externality upon environment in the "*adoption and diffusion*" phase is fairly new. Thus, the private return on eco-innovation is lower than its social return as only the innovator bears the R&D costs whereas the whole society benefits from the environmental improvement that has a public good character. These double market failures reduce private incentives to invest in environmental R&D and justify the need for the "*regulatory push-pull*" effect proposed by the seminal article of Rennings (2000). However, in spite of the incentivizing role of regulation, eco-innovation cannot be considered to be a systematic response to regulation. Rennings (2000) says: "*it can be concluded that contributions on eco-innovation from environmental economics suffer from a simple, mechanistic stimulus-response model of regulation, neglecting the complexity of determinants influencing innovation decision in firms*." (p. 325) "*While environmental economics tells how to assess environmental policy instruments, innovation economics has led to insights about the complexity of factors influencing innovation decisions*." (p. 324). This is why, innovation economists have tried to answer the question to whether eco-innovations can be treated as normal innovations or if a specific theoretical frame is needed. Since the 1990's[6], they have begun to study the impact of the traditional determinants, the "*demand-pull*" and "*technology-push*" ones, on the eco-innovations[7].

The "*technology-push*" determinants, also called supply-side determinants, are stemmed from the famous Schumpeter's works (1934, 1950) and considered as the first generation of the innovation models (Bush, 1945). According to this view rather linear, innovations are driven by scientific and technological progress (Freeman, 1982; Mowery and Rosenberg, 1979; Baumol, 2002). The more we accumulate the knowledge, the more we innovate. These innovations can increase the differentiation between products and thus reduce competition, improve firm's reputation and/or increase performance through cost reduction. We can note that the "*technology-push*" category also includes the organizational innovations (the adoption of environmental management systems, extended producer responsibility) and

[6]Even if articles were published during the 1990s (Green et al., 1994; Cleff and Rennings, 1999), it is Rennings (2000) who will interest innovation economists to the subject which will accelerate the work in this area.

[7]For a literature review on eco-innovation determinants at firm level see Pereira and Vence (2012)

industrial relationships (supply chain pressure, networking activities) (Oltra et al., 2008; Doran and Ryan, 2012).

The "*demand pull*" approach highlights the market demand roles in the technical change process (Griliches, 1957)[8]. Users represent a key element of the selection environment for innovations and have a deep understanding of the requirements that innovation must meet (Fagerberg et al., 2015). One first role is the level of the demand, as such, on the market or future markets of the innovation (Schmookler, 1962, 1966). The more important the demand or the expected benefices are, the more we are encouraged to innovate. The second role that can be played is associated with the dimension of "*learning by using*". Indeed, an innovation often encounters limits following its use and in general, users make some feedbacks to improve this innovation or to express some other needs which can be satisfied with new inventions. Users are considered as the pioneers of a new trend based on two criteria: experience and intensity of their needs. In this field, we can note the contribution of von Hippel (1986, 2001, 2005) who is considered as the main supporter of the "*bottom-up innovation*" notion where users are in the heart of the design of technical devices. He proposed the notion of "*lead users*" 1986 to qualify these consumers that develop their own inventions to resolve their own problems where there are no solutions on the market; and the "*self-manufacturers*" 2005 those who regency the use of available tools to adapt them to specific needs.

Concerning the empirical studies, the majority of analyses confirm the positive impact of the environmental regulation on the eco-innovation measured essentially by existing and/or anticipated regulations and subsidies. For example, Cleff and Rennings (1999) using Mannheim Innovation Panel (1996) and telephone survey, establish a causality effect between regulation and process eco-innovation. Product-integrated eco-innovation however are determined by 'soft' regulation (e.g. labels, eco-audits). Frondel et al. (2008) analyse a variety of factors impacting the firm's choice between "*cleaner products and production technologies*" and "*end-of-pipe technologies*" in 7 OECD countries and find that regulation has a significant impact only on the "*end-of-pipe technologies*". Horbach et al. (2013) compare the determinants in two different countries France and Germany and find, inter alia, that there is a significant impact of the regulation but no significant one of the subsidies. Cuerva et al. (2014) arrive to same conclusion concerning the role of subsidies on Spanish agri-

[8]This is the second generation of the innovation models.

foods SMEs. Analysing European SMEs dataset, Triguero et al. (2013) confirm the positive effect of regulation on organizational eco-innovations. Mazzanti and Zoboli (2005), Rehfeld et al. (2007), Horbach (2008), among others, confirm the positive effect of the compliance with (future) environmental regulation.

Many papers tested the impact of "*technology-push*" determinants on the eco-innovation. For example concerning the R&D role, Mazzanti and Zoboli (2005) revealed that environmental R&D is one of the most important drivers for eco-innovation in manufacturing Italian firms. Horbach (2008) and Rehfeld et al. (2007) also find positive impact using data derived from German firms contrary to Kammerer (2009) who did not find a significant correlation. Cuerva et al. (2014) indicate that technological capabilities measured by R&D and human capital, foster the conventional innovation but not the eco-innovation in low-tech Spanish SMEs. Frondel et al. (2008) show, in contrast with their conclusion about regulation, that there is a significant positive effect of R&D only on clean technologies. This result is confirmed by Hammar and Löfgren (2010) when they analysed the impact of R&D on the investment in end-of-pipe technology in Swedish firms. Reducing costs, and subsequently increasing profit margins, is a key element to environmental innovation too. This statement is supported by Green et al. (1994) for British companies and Horbach (2008) for German ones. Horbach et al. (2013) also confirm this effect for innovations reducing energy consumption, inputs use and CO_2 emissions. These findings are very close to those of Rave et al. (2011). Frondel et al. (2008) reveal a positive correlation with eco-innovation process while Demirel and Kesidou (2011) point out the positive link between R&D expenditures and saving costs.

It is hard to find adequate measures to test all the nuanced notions of the "*demand pull*" category. Many articles used the expected customer demand and find positive impact especially on product eco-innovation even under greatly different conditions. Indeed, product innovation allows firms to differentiate their product on final market and hence increase their competitive advantage (Reinhardt, 1998). Using UK dataset, Green et al. (1994) demonstrate that the prospect of expanding market share consist an important factor impacting the product eco-innovation. Market goals play a determinant role only on product eco-innovation in Cleff and Rennings (1999) and Triguero et al. (2013) papers. Horbach (2008) however, find a positive impact of the expected increase in customer demand on overall eco-innovation. Rehfeld et al. (2007) and Kammerer (2009) introduce the consumer satisfaction or benefits in their studies. Rehfeld and her co-authors (2007) note that satisfying customer's private needs have strongly significant positive effect on product eco-innovation but not to process eco-innovation. Kammerer (2009) studies the impact of the private benefits of customers such as "*cost/energy savings through more efficient appliances, improved product quality and durability, better repair, upgrade, and disposal possibilities, as well as reduced health impacts*" (p4) . From then on, these benefits have been emphasized in the eco-marketing literature as a prominent element to generate stronger consumer demand (Ottman and Books, 1998, Reinhardt, 1998). The results show that firms concerned by customers benefits are more likely to implement product eco-innovation[9].

The literature of the innovation and environmental economics propose a large number of drivers. These latter belong mainly to one of the following three categories, "*environmental regulation*", "*technology-push*" and "*demand-pull*" one. The analyses developed concern essentially firm and industry level studies. Nonetheless, the transition from a micro to a macro level cannot be done by a simple aggregation i.e. the efficiency of the national system as a whole is not only the juxtaposition of productive units' performances. We must take into account the capacity to promote a favourable environment and ensure coordination between the individual components. This is why it's important to understand what the macroeconomic determinants of innovations are and check if these determinants are also valid for the eco-innovation and/or if others are needed.

1.2.2 The macro Innovations' determinants

The important role of innovation as a driver of growth has enabled it to occupy a privileged place in the macro-economic theory from the 1950s (Solow, 1956, Romer, 1986, Lucas, 1988). It is the theory of exogenous growth, initiated by Solow (1956), which states that innovation (or what he called technical progress) is at the origin of a sustained productivity growth but remains silent on the origins and mechanisms of this technical progress. It took 30 years, with the article of Romer (1986)[10], to elaborate the endogenous growth models, i.e. growth models where technical change is treated as an endogenous determinant of economic growth. According to Romer (1986), innovation is an increasing return activity that generates knowledges. These knowledges have a positive spillover, "*positive external-*

[9]The articles testing the trichotomy proposed by Rennings (2000) are summarized in Table 7.
[10]We can also quote the contribution of Lucas (1988).

ity", which benefits not only to the innovative firms but also to all the society. So innovation relies on economic agents behaviours and it is at the origin of the economic growth.

New growth theories and thereafter international trade theories emphasize the virtues of trade liberalization on the efficiency of the firms at the micro scale and the technology diffusion at the macro level. In their view, liberalization has two positive effects: a static effect generated by the transfer of resources, and a dynamic effect resulting from the growth in factor productivity through increased technology imports and increasing competition between firms (Rodrik, 1993). In this context of openness, States play an important role through two actions. The first one seeks to protect domestic firms from competition through non-tariff barriers, i.e. establishment of strict standards on working conditions, product quality or environmental criteria. The second action influences the creation of a comparative advantage through the incentives given to firms to innovate. Environmental regulations within the European Union (EU), for example, could partially protect European firms from the competition of foreign firms not complying with these standards on the European soil and also could guide local firms towards eco-innovation which will give them a first mover advantage in the way environmental standards are adopted in other countries.

Endogenous growth and international trade theories introduce finer assumptions into neo-classical models but don't break with this mainstream. Some researchers however, not satisfied by the basic premises and features of neoclassical economics, proposed the "*National Innovation Systems*" (NIS) approach to understand competitiveness at the country level and to identify determinants of innovation (Edquist, 2001)[11]. The NIS is defined as a "*set of institutions that (jointly and individually) contribute to the development and diffusion of new technologies. These institutions provide the framework within which governments form and implement policies to influence the innovation process. As such, it is a system of interconnected institutions to create, store, and transfer the knowledge, skills, and artefacts which define new technologies*" (Metcalfe, 1995, p.24). We attribute the origin of the NIS concept to the economists Freeman (1982, 1989) and Lundvall (1985, 1988). This approach emerged at a specific moment in history "*precisely when economic globalization was accelerating during the 1980s and when international competition among companies*

[11] "*I have always been annoyed by how, in spite of its limited relevance and validity, neo-classical economics has pursued the pretentious intention to colonize all thinking about the economy. One important motivation for my interest in innovation and innovation systems is actually that when you focus on innovation it becomes absolutely clear that the neoclassical assumption about agents making choices between well-defined alternatives cannot apply. (Lundvall interview, 20 October 03)*" (Sharif, 2006, p.754).

was intensifying. In particular, Japan was emerging as a new global economic powerhouse, dominating a variety of industrial sectors and moving up through the league tables as measured by gross national product" (Sharif, 2006, p.761) [12].

This approach is based on three main theoretical contributions. First, Lundvall asserts that learning is the most important process and knowledge is the most important resource of innovation. The interactive learning theory (1988; 1998; 2002b; 2010; Lundvall and Johnson, 1994) emphasize the role played by interactions between individuals belonging to different social and economic structures and institutions to facilitate the learning process and the knowledge accumulation. Second, the evolutionary theory of technological change puts the light on the strategic role played by the knowledge and learning to explain the heterogeneity between agents (2007). Indeed, economic agents cannot be treated as homogenous through a "*representative agent*", but we have to consider their behavioural differences due to differences in the used technologies, internal sources, administrative organizations, external environment, etc. According to this literature, innovation improves the performance of firms to face the natural selection at micro level and it is the driving force of long-run economic development (Nelson and Winter, 1982; Dosi and Nelson, 1994; Mulder et al., 2001; Nelson and Winter, 2002). That's why in the evolutionary theory, institutions whose interactions determine the performance and innovative capabilities of domestic firms are considered as important objects of study. The last theoretical field is the institutional theory (Freeman, 1989, Freeman, 1995; Edquist, 1997). It seeks, amongst others things, to understand the impact of institutions on individual behaviour of economic agents; on differences of national orientations in terms of accumulation of physical and human capitals and on the capacity of countries to use them. For the new institutional economics, institutions are intended to reduce uncertainties which decrease transaction costs, ensure stability, favour the clusters' emergency and counter market imperfections. This mechanism has a great importance on economic performance (North, 1990, 2003). We must then integrate institutional elements in the analysis of technological change and consider the crucial role of institutions to generate and strengthen innovation capacity at national level. To sum up, NIS stresses the importance of firms as individual entities, the importance of their interactions with each other (competition, cooperation, etc.) as well as the prominent role of institutions in the

[12] We are also living a similar hectic period with the emergence of China as a new economic power, the advent of the global financial and economic crises and the acceleration of the environmental concerns. That can justify, in our point of view, the need to theoretical and empirical framework to develop and understand a "*National Eco-Innovation System*".

innovation system[13].

More recently, Furman et al. (2002) proposed the concept of National Innovation Capacity (NIC) that combines the NIS concept with the endogenous growth theory and the cluster-based theory of national industrial competitive advantage (Porter, 1990). This concept provides a more comprehensive view of national innovation capabilities by considering local, regional and national elements through the study of three building blocks: the common innovation infrastructure, the country's industrial clusters and the strength of linkages between them.

All these fieldworks inspired a countless number of empirical researchers to detect the determinants of innovation at macro level. Many of them are based on the endogenous growth model. Among the most recent papers, Bayar (2015) studied a sample of 10 European countries from 1999 to 2012 and found that innovation, proxied by the number of patents grants, is 1) positively impacted by R&D expenditures, economic growth, financial development, domestic savings and high-technology exports, 2) not impacted by foreign direct investment and 3) negatively or not impacted by inflation (depending on the econometric method used). Guloglu et al. (2012) examined the rate of patents on the G7 countries over the period 1991-2009 and conclude that R&D, high technology exports, and FDI have a positive effect on technological progress, the rate of interest have a negative one, whereas the trade openness seems to not impact the technological progress. In contrast, Khan and Roy (2011) found, comparing OECD and BRICS countries, that trade openness may have a positive effect on innovation. They also found that productivity of R&D expenditures in terms of increased innovation activities is significantly higher in the OECD countries than in the BRICS. The enrolment in tertiary education, however, has a positive impact on the BRICS but no significant one for the OECD countries. Krammer (2009) examined 16 Eastern European countries over the period 1991-2011 using a range of economic methods and control variables. He highlighted the positive role of R&D commitments, existing national knowledge, as well as the policy measures and globalization. Measures of transitional

[13]There are two different scales to study institutions in the NIS fieldwork. A narrow scale which is limited to the consideration of organizations and institutions involved directly in the process of generating knowledge, research, exploration (research centres, R&D departments, technical institutes, universities, etc.) and a larger scale which explains that institutions regarded in the narrow vision are embedded in a broader socio-political-economic system and that all these institutions indirectly involved must be taken into consideration. This article considers the determinants of the narrow vision since that it focuses on the European countries which are developed ones and so the indirect institutions are supposed rather equivalent, stable and favourable to innovations.

downturn and industrial restructuring decrease the propensity to patent. Eyraud et al. (2011) explored empirically the drivers of the renewable green investment using a variety of control variables. They found, among others, that public policy such as high fuel prices, and macroeconomic factors such as economic growth and interest rates, are important factors. Coe et al. (2009) took back the article of Coe and Helpman (1995) on the "International R&D Spillovers" and extended it by including institutional variables. They also revisited it by using newer panel co-integration estimation techniques and expanded data set. The results confirm the positive impact of domestic and foreign R&D capital stock and highlight the impact of human capital about the national productivity. They also give strong evidences on the role of institutions on the degree of R&D spillovers and to explain the differences between the national productivity. Varsakelis (2006) gave evidences to the NIS theory as well by examining the role of education (such as scores and number of students related to scientific subjects) and political institutions (for example civil liberties and press freedom) on innovation activity (number of patents) in 29 countries during the period 1995-2000. Furman and Hayes (2004) and Hu and Mathews (2005) extended the empirical study concerning the 17 OECD countries of Furman et al. (2002) on the NIC to, respectively, 29 OECD countries and East Asian "tigers". They showed more or less the same results.

To recap, this first section gives an overview about the economic fields dealing with the drivers of (eco)innovations. Certainly, each one of them could serve as a theoretical framework to analyse the determinants of the eco-innovation at macro level. However, it may be good to have a view of most, if not all, of the related theories developed so far since they can all shed light on the issue. In what follows, an empirical study will be conducted to test the influence of different determinants on the eco-innovation.

1.3 Data and descriptive analysis

1.3.1 Data

Several data source have been used to construct our final dataset. Further details on definition and data sources are available in Table 1.1[14].

[14]Updated data for the last time in November 2016

Table 1.1: Variables list and definition

Symbol	Definition/Measures	Source
ECOPAT	Environmental innovations: Green and inventive technologies	OECD
R&D	Research and Development expenditures (constant 2010 PPP US dollar, per Millions)	OECD
DM	Household final consumption expenditure (constant 2010 PPP US dollar, per Millions)	OECD
EDU_{gdp}	Government expenditures on education (as % of GDP)	World Development Indicators
OPENNESS	Sum of exports and imports over GDP	World Development Indicators
EPS	Environmental Policy Stringency Index	OECD
EPS_{market}	Environmental Policy Stringency Index of market-based instruments	OECD
$EPS_{nonmarket}$	Environmental Policy Stringency Index of non-market-based instruments	OECD

1.3.1.1 Eco-patents as a proxy of eco-innovation

This study uses a variable based on the number of environmental patents taken out from the OECD (ECOPAT here after). "*The patent statistics presented here are constructed using data extracted from the Worldwide Patent Statistical Database (PATSTAT) of the European Patent Office (EPO) using algorithms developed by the OECD. (...) The relevant patent documents are identified using search strategies for environment-related technologies (ENV-TECH) which were developed specifically for this purpose. They allow identifying technologies relevant to environmental management, water-related adaptation and climate change mitigation. An aggregate category labelled "selected environment-related technologies" includes all of the environmental domains presented here*"[15].

Since we are interested in international comparisons and in order to avoid some of the abovementioned problems in the literature review section, the patent grants are taken according to inventor's country of residence, focusing on those having sought patent protection in at least two jurisdictions and all patents are taken according to their priority date. Indeed, we chose the inventor's country of residence rather than applicant's country to focus on determinants that drive the innovation and not the place where this latter is used or diffused. Secondly, the patent family is a set of the equivalent patent applications corresponding to a

[15] http://stats.oecd.org/OECDStat_Metadata/ShowMetadata.ashx?Dataset=PAT_COL_RATES&Lang=en&backtodotstat=false

single invention listed in several patent offices. It has been argued that using data based on the "claimed priorities", i.e. family size comprising at least two offices, is the most appropriate level when we are in analysis across countries since it takes only high-value patents without placing an excessive constraint on narrow technological fields[16]. Finally, the use of priority date, which is the earliest year of application and so the nearest date to the inventive activity, also facilitates the comparison of innovation across countries since it gives uniformity in measuring innovation because it does not dependent on any differences in application rules set by the different patent offices (De Vries and Withagen, 2005). We have also to notice that the use of patent accounts as a dependent variable may raise concerns about a scale effect since larger and wealthier countries may increase the number of patent applications (Krammer, 2009). To correct this scale problem, we choose to normalize it by GDP ($ECOPAT_{GDP}$).

1.3.1.2 Measuring the Innovation Determinants

The most serious problem that a cross-country study meets is to find reliable, commensurable measures of the stringency of environmental policies. Stringency can be defined as the explicit or implicit cost imposed on any environmentally harmful comportment (Albrizio et al., 2014; Botta and Koźluk, 2014; Brunel and Levinson, 2013; Koźluk and Zipperer, 2015)[17]. Over the last twenty years, EU countries have implemented a wide range of policy instruments that can be grouped into four categories: "*Market-based instruments*", "*Command and Control regulation instruments*", "*Voluntary agreements*" and "*Information-based instruments*" (Zuniga et al., 2009, Crespi et al., 2015) [18]. It is easy to imagine the difficulty of measuring the stringency of these elusive instruments across countries and time to make feasible empirical research at a macro, cross-country level.

This study uses the new environmental policy stringency (EPS) index of Botta and Koźluk (2014). The index transforms quantitative and qualitative information contained in normative policy instruments into a comparable country-specific measure. To do so, Botta

[16]See Haščič and Migotto (2015) and Martinez (2010) for more arguments.

[17]For example taxes, subsidies, stricter emission limit values have all the same interpretation i.e. implying higher stringency. They increase the opportunity costs of polluting or enforce environmental standards and therefore provide advantages to environment-friendly activities (Botta and Koźluk, 2014).

[18]This paper focus, as almost all previous works on the determinants of environmental innovation, on the first two categories because they represent the vast majority of policy instruments used, they are easier to observe and quantify and they are more restrictive since they impose explicit obligations. The two last instruments, also called "*soft regulations*" are very context-specific and look for stimulating discretionary activities.

and Koźluk (2014) rely on the taxonomy developed by De Serres et al. (2010) and weight equally the sub-components of each category as shown in (Figure 1.1). The EPS index ranges from 0 to 6, where 0 translates a nonexistence of any environmental regulation and 6 is, in contrast, a very high level of stringency.

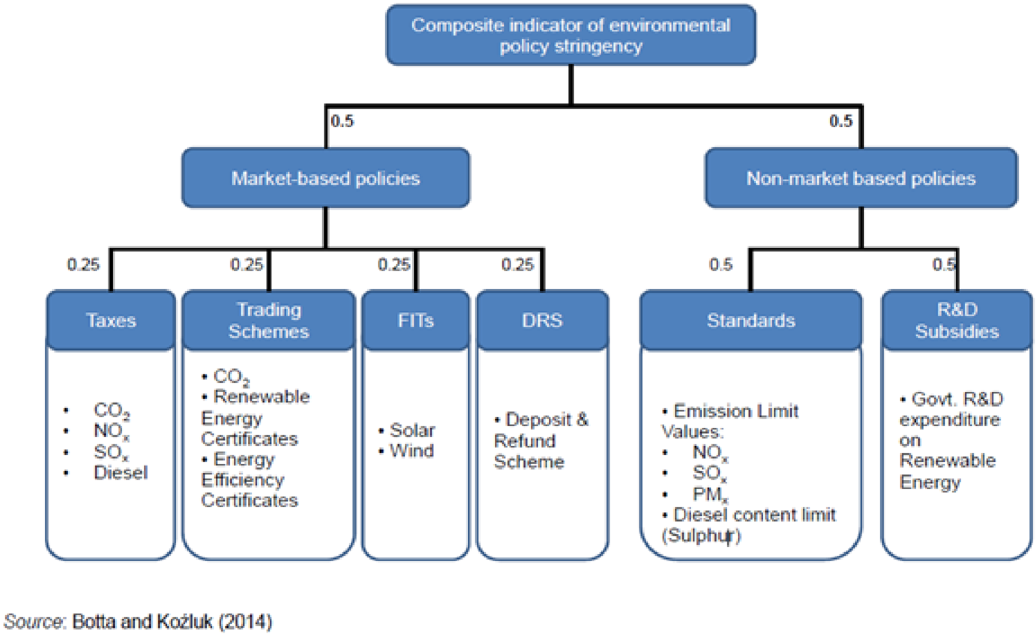


Figure 1.1: Structure of the Environmental Policy Stringency Index

Since there is a large consensus in literature considering that market-based instruments are more likely to induce innovation than command and control ones (Malueg, 1989; Jaffe et al., 2002; Fischer et al., 2003; Popp et al., 2010), we will distinguish between the two kinds of regulation to test their relative impacts (EPS_{market} and $EPS_{nonmarket}$).

In the "*technology-push drivers*" category, it is commonly used in empirical analysis to take the R&D expenditures as proxy of technological capabilities. Data on gross domestic expenditure on R&D were obtained from the OECD database. As for patent data, we normalize the R&D expenditures by GDP to avoid the scale problem ($R\&D_{GDP}$). For the "*demand-pull drivers*" category, the demand per capita (DM_{PC}) and government expenditures on education as percentage of GDP (EDU_{GDP}) are taken as proxies. The idea behind this is that richer and more highly educated populations are more sensitive to environmental concerns and put more pressure on the demand side.

The government expenditures on education may also give an idea about the "*institutional determinants*" since higher education sector (university, etc.) gives an indication of the relationship between the scientific sphere and the rest of the innovation system. Concerning the "*institutional determinants*", it is also important to capture the openness of the national system to the international trade. Due to the globalization, a national's performance depends not only on its own competences but also on its trade partners' competences (Coe et al., 2009). So States are putting more and more measures in place to promote this exchange. To capture this aspect, we built a variable called OPENNESS that computes the foreign trade as a proportion of GDP (Coe et al., 2009; Khan and Roy, 2011; Guloglu et al., 2012, Huňady and Orviská, 2014) i.e.,

$$\text{Openness} = \frac{\text{Value of import} + \text{Value of export}}{\text{GDP}}$$

This measure gives an idea about the degree of competitiveness that local firms face. It correlates with the ability of local firms to target larger international markets and with the ability of foreign firms to exploit their innovations in the local economy (Furman and Hayes, 2004). This international trade also increases technological imitation and the foreign advanced knowledge diffusion.

Some last points concerning the data have to be explained. To begin with, we have to note that our data are strongly balanced but there are some missing values concerning the non-annual census of some data (representing less than 5%) that were fulfilled by interpolating the average of the two values existing before and after the missing value. We also used lagged variables to allow sufficient time for economic agents to respond to determinants by innovating. A 2-year moving average has been chosen (Furman and Hayes, 2004; Krammer, 2009).

1.3.2 Descriptive analysis

Our sample covers 12 European countries (Austria, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Norway, Spain, Sweden and United-Kingdom (UK)), over a time period of 1990-2012 which makes a total of 276 observations. Mean and standard deviations of the employed variables are reported in Table 1.2, while pairwise correlations appear in Table 1.3.

Table 1.2: Summary statistics

Variable label	Mean	Std. Dev.	Min.	Max.
$ECOPAT_{gdp}$ $^{(*)}$	4.45	3.38	0.24	19.96
EPS	1.87	0.82	0.48	4.41
EPS_{market}	1.23	0.84	0.08	4.05
$EPS_{nonmarket}$	2.50	1.08	0.63	5.50
$R\&D_{gdp}$	0.02	0.01	0.004	0.04
DM_{pc} $^{(**)}$	1.89	0.59	1.156	10.06
EDU_{gdp}	5.53	1.15	3.64	8.62
OPENNESS	74.33	31.10	33.98	190.11

(*) Values are multiplied by 10^4 (**) Values are multiplied by 10^{-4}

Table 1.3: Cross-correlation table

Variables	$ECOPAT_{gdp}$	EPS	EPS_{market}	$EPS_{nonmarket}$	$R\&D_{gdp}$	$R\&Dpr_{gdp}$	$R\&Dpu_{gdp}$	DM_{pc}	EDU_{gdp}	OPENNESS
$ECOPAT_{gdp}$	1.00									
EPS	0.51	1.00								
	(0.00)									
EPS_{market}	0.22	0.81	1.00							
	(0.00)	(0.00)								
$EPS_{nonmarket}$	0.60	0.89	0.46	1.00						
	(0.00)	(0.00)	(0.00)							
$R\&D_{gdp}$	0.77	0.37	0.10	0.48	1.00					
	(0.00)	(0.00)	(0.10)	(0.00)						
DM_{pc}	0.09	0.22	0.17	0.20	-0.10	1.00				
	(0.17)	(0.00)	(0.01)	(0.00)	(0.10)					
EDU_{gdp}	0.49	0.23	0.00	0.35	0.44	-0.05	1.00			
	(0.00)	(0.00)	(0.98)	(0.00)	(0.00)	(0.45)				
OPENNESS	0.03	0.09	-0.11	0.21	0.01	-0.01	0.07	1.00		
	(0.61)	(0.17)	(0.09)	(0.00)	(0.89)	(0.92)	(0.27)			

Standard errors in parenthesis

For the countries under analysis, on average, 463.97 patents are granted per country and per year in at least two different offices. This type of patents represents 9.36% of the total patents and have increased by 213% from 2995 in 1990 to 9371 in 2012. In this race for environmental patents, Germany is far ahead with an average of 2739.5 followed by France and the United Kingdom with 745.5 and 585 eco-patents granted respectively. At the bottom of the scale we find Norway (65) and Ireland (24) (see Figure 1.2).

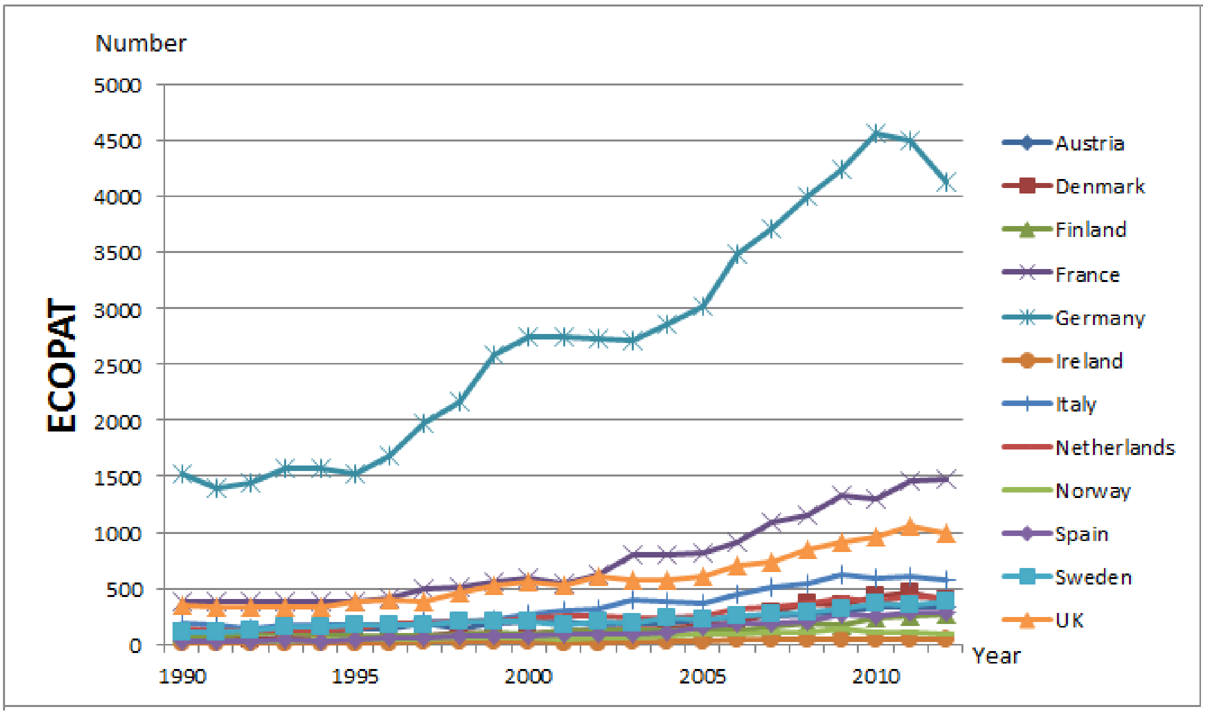


Figure 1.2: Evolution of international Eco-patents

When normalized by GDP, the average number of ECOPATENT$_{GDP}$ becomes 0.0004 and the standard deviation is 0.0003 with a cross country difference ranging from a minimum of 0.000024 for the Spain in 1991 and a maximum of 0.002 for the Denmark in 2011 (Table 1.2). On average over the 23 years, Germany remains ahead (0.0009), followed by Denmark (0.0008), Finland (0.0007), Austria (0.000639) and Sweden (0.000637) (Figure 1.3).

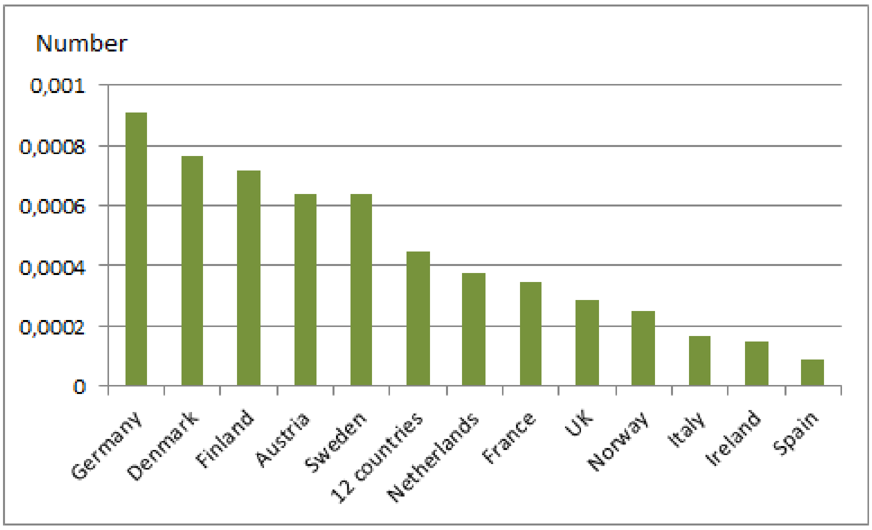


Figure 1.3: Mean of international Eco-patents per GDP

It is interesting to mention the sharp increase of the Danish and Finnish environmental patenting activity which places the two countries in first (0.0017) and second position (0.0013) in 2012 in front of Germany (0.0012). At the bottom of the ranking we find Norway (0.00025) and Italy (0.00017) followed very closely by Ireland (0.00015) and Spain (0.00009) (Figure 1.4).

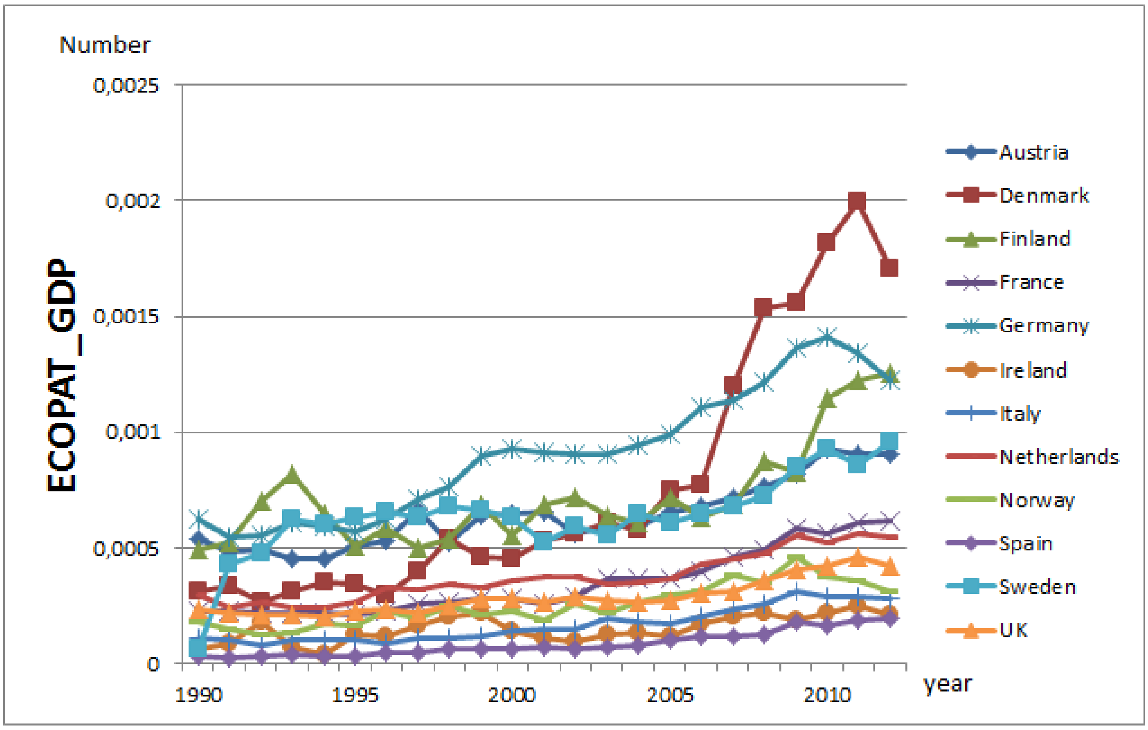


Figure 1.4: Evolution of international Eco-patents per GDP

In order to explain these findings, if we look at the policy stringency, we generally perceive that regulation was more restrictive in 2012 (3.08 on average on a scale of 6) than it was in 1990 (0.93). Market-based instruments were very uncommon during 1990 not exceeding a stringency threshold of 0.42 exaequo for Finland, France, Germany, Ireland and Italy. For non-market instruments Netherlands was well ahead with a score of 3 followed by Austria and Germany (with a score of 2). Denmark and Sweden were in 3^{rd} place (1.625). In 2012, Denmark took the lead with 4.18 followed by Finland with 3.345 and UK with 3.325. At the bottom of the standings were Ireland (2.05), Spain (2.21) and Austria (2.945). Market-based instruments also rose from 0.33 on average in 1990 to 2.04 but remained far behind non-market instruments with 4.13 (1.54 in 1990). In 2012, regarding these instruments, the UK was leading with 3.40 followed by Denmark (3.12) and France (2.63). The lowest countries were Ireland (0.85), Finland (1.32) and Germany (1.52). The podium for non-market included Finland (5.38) Denmark (5.25) and Netherlands (5). The lowest countries were Ireland, Italy and UK sharing the same position with 3.25 and Spain with 2.75. The UK was the only country where Market Based Instruments were more stringent than non-market ones (see Figure 1.5 and 1.6). Evolution of the environmental policy stringency by country is in Appendix .1.

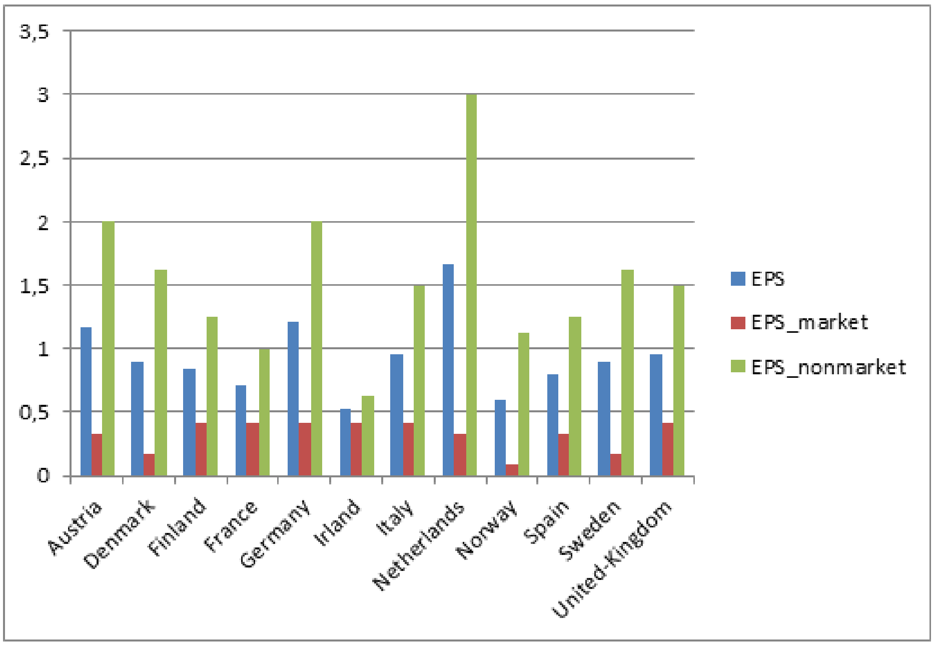


Figure 1.5: Average of the environmental policy stringency(1990)

(EPS index ranges from 0 to 6)

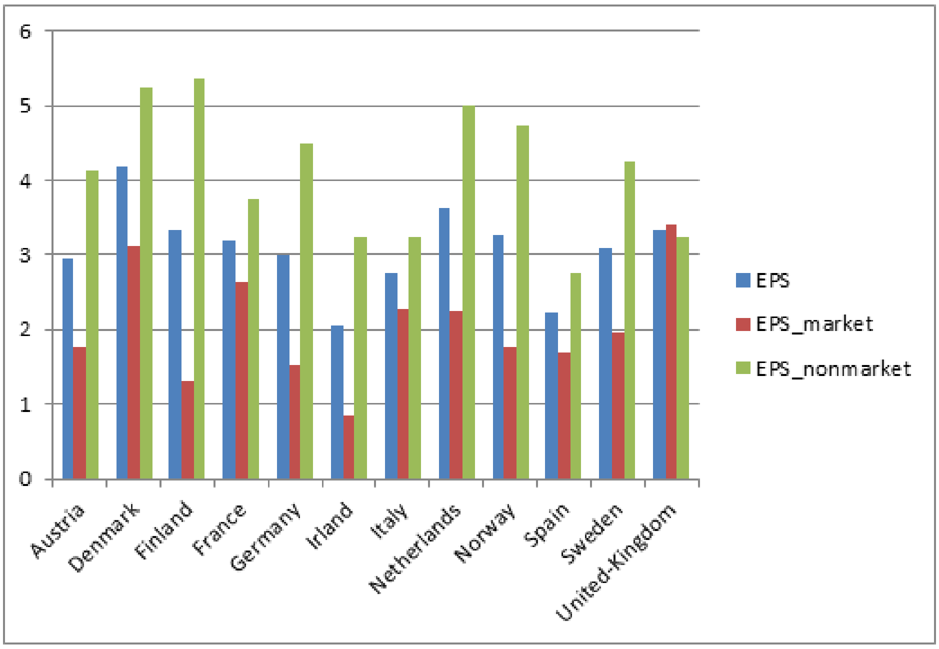


Figure 1.6: Average of the environmental policy stringency (2012)

(EPS index ranges from 0 to 6)

Concerning the *technology-push* determinants, if we look at the behaviour of the different countries in terms of R&D we notice that Finland, Sweden and Denmark are the ones with the strongest growth and which earned them the first three places. Germany started the race at the top but had known a slight increase compared to the other countries, hence its position in 5^{th} place (0.287) in 2012 and 3^{rd} place on average over the 23 years (behind Sweden and Finland but before Denmark) (Figure 1.7). France has not experienced strong growth and even declined from 1990 (0.023) until 2007, when it reached its lowest level (0.020) before realizing a slight increase in 2009 without however returning to its 1990 level in 2012 (0.022). A surprise about the UK which occupied only the 8^{th} position on average over the 23 years and the 10^{th} position in 2012 even though it was in 3^{rd} position if we only look at the amounts spent in R&D (Figure 13 in the Appendix .2). Austria is the country with the most stable growth, which earned it the 4^{th} place ahead of Germany in 2012 (0.0289). To finish with, we find Ireland, Italy and Spain at the bottom of the scale. Interestingly, the groups remain more or less the same as those of the ECOPAT$_{GDP}$, with the group of leaders (Austria, Denmark, Finland, Germany and Sweden), the group of latecomers (Ireland , Italy and Spain), France, Netherlands, Norway and United Kingdom are in the intermediate group. This brings us to assume that R&D strongly impacts eco-innovations.

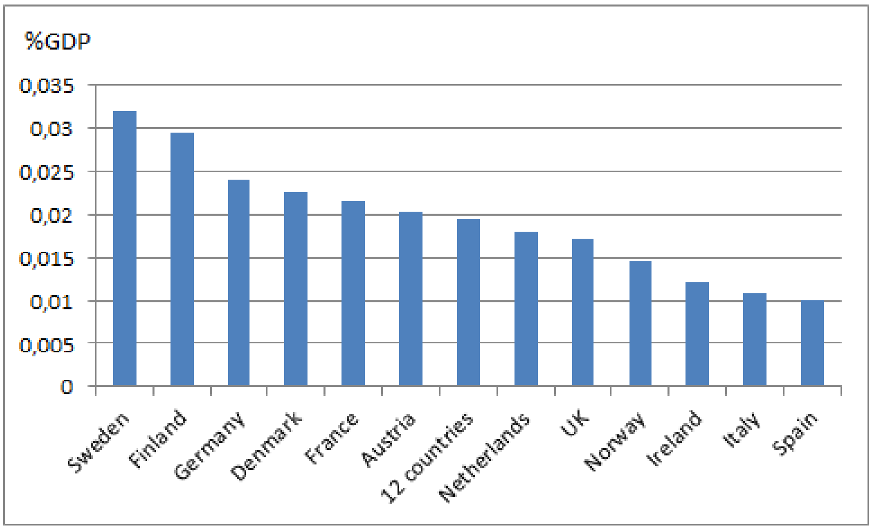


Figure 1.7: Mean of R&D expenditures per GDP

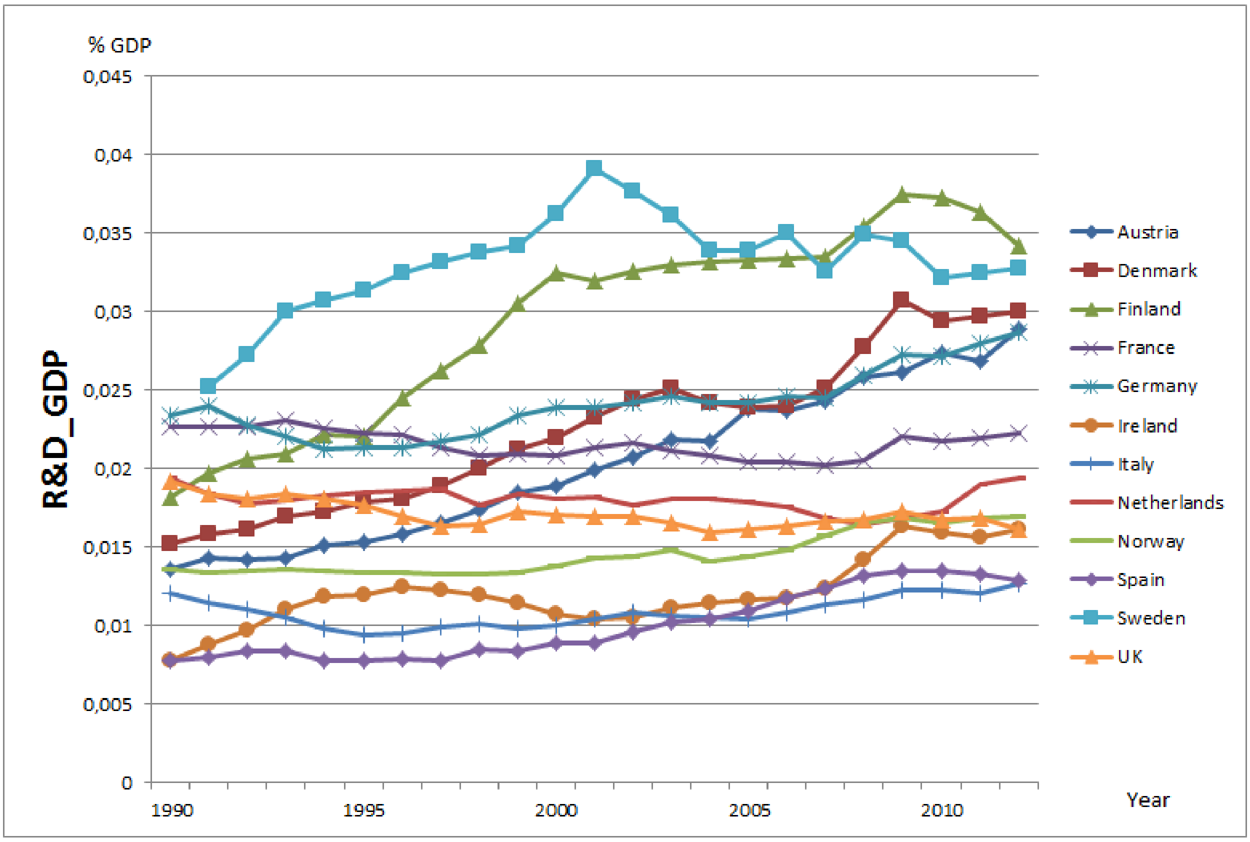


Figure 1.8: Evolution of R&D expenditures per GDP

Figure 1.9 gives an idea about the evolution of the demand expenditures per capita. Roughly speaking, demand has been increasing with a decline around 2009. This decline can be reasonably explained by the global economic crisis of 2008. The demand expenditures resumed their growth thereafter mainly for Austria, Germany, Finland, Sweden. Countries that stabilized their demands are Denmark, France and the UK. In contrast, in Spain, the

Netherlands, Italy and Ireland the demand continued to fall until 2012. We can therefore say that the countries that have maintained their demand expenditures per capita are those that perform better in eco-innovation, while those that have continued to decline are the ones that have innovated the least.

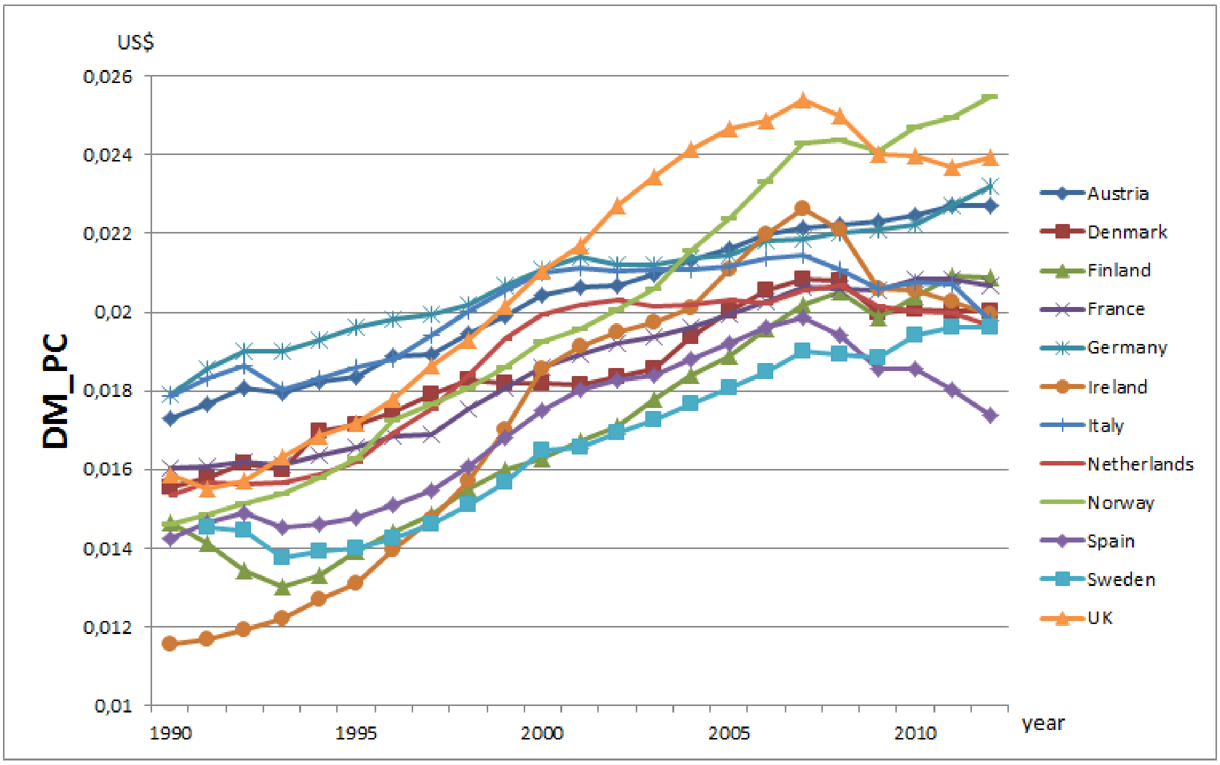


Figure 1.9: Demand expenditures per capita

Regarding expenditures on education, the ranking generally follows the other determinants with Denmark, Sweden, Finland and Austria which are among the top 5. Italy and Spain are the last two countries (Figure 1.10). Nevertheless, there are a few surprises with Norway in second position and Ireland ahead of the UK and Germany, which are are respectively in 9th and 10th positions (Evolution of the Government expenditures on education by country is in Appendix .3))[19].

[19]We have to note that data of EDU_{GDP} may refer to spending by the ministry of education only (excluding spending on educational activities by other ministries) and that government expenditure appears lower in some countries where the private sector and/or households have a large share in total funding for education (The world bank). For example in Germany, the apprenticeship rate is very high and apprenticeship is the responsibility of the Länder and not the federal state that spends nothing in educational matters.

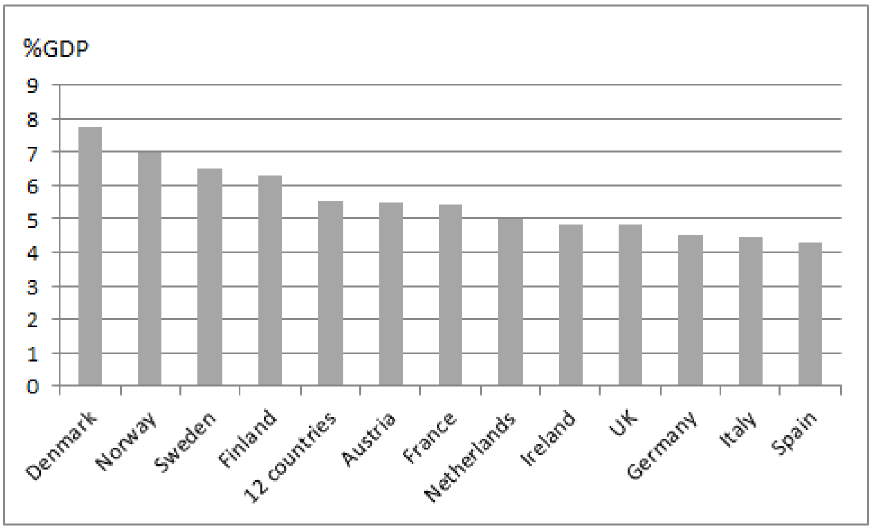


Figure 1.10: Mean of Government expenditures on education (as% of GDP)

By analysing the openness variable, we observe that countries follow more or less the same trend with a first decrease around 2002/2003 following the internet bubble and a second in 2009 following the subprime crisis in 2007 and the economic crisis in 2008 (the decline occurred in 2011 in Ireland) (Figure 1.11). This shows that the trade relations of countries are interconnected and that a shock impacting one or more countries spreads more or less quickly to the others.

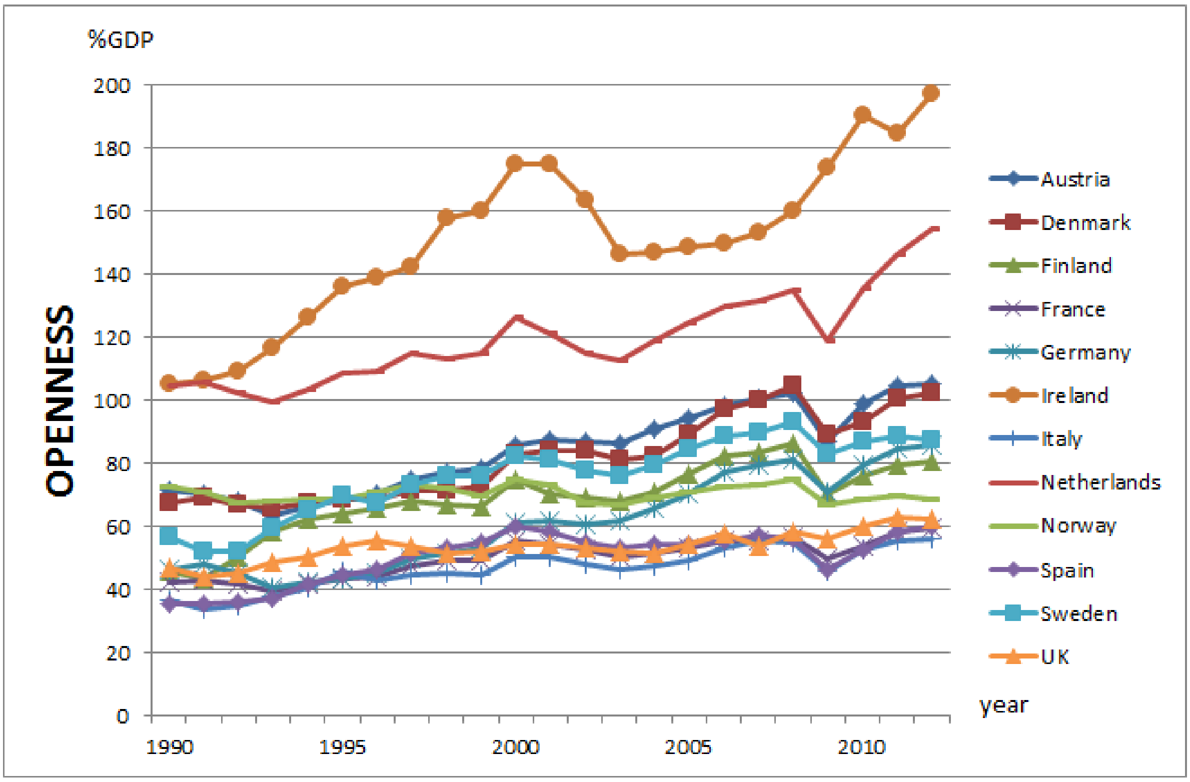


Figure 1.11: Openness evolution

However, when looking at the ranking of countries it is quite surprising to find the 5 largest European economies occupying the 5 places at the bottom and Ireland and the Netherlands occupy largely the first two places at the top (Figure 1.12).

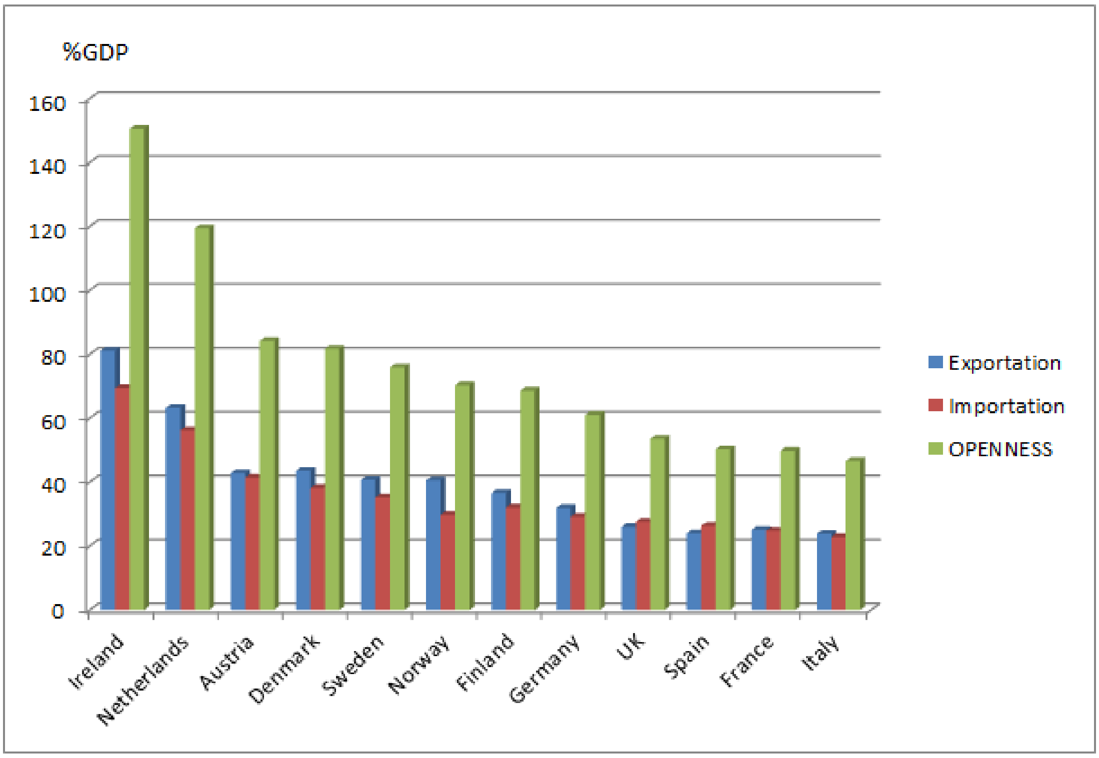


Figure 1.12: Mean of Openness

1.4 Empirical analysis and results

1.4.1 Methodology

In this study, the econometric method of panel data is used in order to exploit the extra information provided by the panel data framework. To do so, the following linear reduced form equation is estimated. This builds on a simple generalization of Romer (1986) and Jones (1995)' specification.

$$\log y_{i,t+2} = \beta_0 + \sum_{k=1}^{K} \beta_k \log x_{k,it} + \epsilon_{it} \tag{1.1}$$

where i indicates countries $i = 1, ..., N$, t represents time $t = 1990, \ldots, 2010$. k refers to explanatory variable k and $y_{i,t+2}$ and $x_{k,it}$ are respectively the dependent and independent variables for country i and time t. β_0 and β_k refer, respectively, to the intercept and the slope parameters to be estimated. ϵ_{it} is a random error term. Given the nature of the data, estimating this model using the OLS method could bias the results. Indeed, since we study European countries which share several similarities and which are economically and culturally linked, we assume that there is potentially heteroscedasticity and correlation across-sections. ϵ_{it} is then assumed to be equal to

$$\epsilon_{it} = \rho_i \epsilon_{i,t-1} + \mu_{it}$$

where the autoregressive parameter can vary across countries with $|\rho_i| < 1$. For these reasons, feasible generalized least squares (FGLS) estimator that is robust to first-order panel-specific autocorrelation and panel heteroscedasticity is used (Baltagi, 2008)[20].

1.4.2 Estimation results

All variables, except the EPS index, are in log form this way the slope parameters can be interpreted in terms of elasticities, are less sensitive to outliers and are consistent with work in this area (Furman et al., 2002; Krammer, 2009). To choose the most suitable estimation method, we run a couple of diagnostic tests[21]. Through the Breusch-Pagan test (1979) a problem of heteroscedasticity is detected. Theoretically, the presence of heteroscedasticity does not bias the estimated coefficients, but it biases the matrix of variance-covariance of these latter. Our data also reveals correlation problems: a contemporaneous correlation, is detected using CDLM (Cross-sectional Dependence Lagrange Multiplier) test and serial correlation problem using the Wooldridge test (2002). These two types of correlation mean that any shock in any year or to any country affects the following years and the other countries. As it is said earlier, we use FGLS to take into consideration these problems detected. We also include year dummies to capture some of the unobserved heterogeneity (Wooldridge, 2002). Wald statistics show that overall significance of all regressions presented is quite high.

Table 1.4 illustrates the regression results. As it is said earlier, the OLS outcome (column (1)) is biased due to the heteroscedasticity and autocorrelation problems. According to the FGLS regression (column (2)), all the explanatory variables have positive and significant effects at a threshold of 5%. A closer look at findings reveals that R&D seems to be the most

[20] Beck and Katz (1995) explain that if the sample size is finite or small, the panel must be "temporal dominant" i.e. the total number of temporal observations must be larger than, or at least as large as, the number cross-section units to be able to use the FGLS method. This is the case in this study.

[21] The results for all the tests are significant at 1%

important element in stimulating national eco-innovation. An increase of 1% in $R\&D_{GDP}$ increases the $ECOPAT_{GDP}$ by 1.18%. This is in line with the findings of the innovation economics - at micro-level- and of the Endogenous growth theory and the NIS - at macro-level - that emphasize the role of knowledge as the most important resource of innovation. This is also consistent with our analysis in the descriptive statistics section which shows that R&D expenditures were broadly in line with eco-innovation's evolution. Another finding that confirms our pronouncement concerns the demand side in which the demand per capita and the educational system seem to have an essential role to play as it is the case for standard innovations (elasticities of 0.84% and 0.31% respectively) (Furman et al., 2002; Varsakelis, 2006; Coe et al., 2009; Krammer, 2009; Khan and Roy, 2011). The international trade (Khan and Roy, 2011) has less important coefficient but still positive and significant (0.11%). Finally our findings support the weak version of the Porter Hypothesis since we find a significant positive impact of the regulation stringency on the environmental innovation. A one point increase in stringency enhances the innovation of 12% (Albrizio et al., 2014; De Santis and Jona-Lasinio, 2015). In addition, the literature related to the PH widely emphasized the different impacts that can have market based and command and control instruments noting that the first category gives more incentives to eco-innovate. The result reported in column (3) confirms this purpose since that both instruments have a significant effect but that market based regulations have a higher positive one (8%) than non-market based instruments (5%).

Table 1.4: OLS and FGLS regressions

	(1) OLS Log($ECOPAT_{GDP}$)$_{t+2}$	(2) FGLS Log($ECOPAT_{GDP}$)$_{t+2}$	(3) FGLS Log($ECOPAT_{GDP}$)$_{t+2}$
EPS	0.10***	0.12***	
	(0.04)	(0.02)	
EPS_{market}			0.08***
			(0.02)
$EPS_{nonmarket}$			0.05***
			(0.02)
Log($R\&D_{GDP}$)	1.54***	1.18***	1.19***
	(0.07)	(0.07)	(0.07)
Log(DM_{PC})	1.24***	0.84***	0.85***
	(0.14)	(0.08)	(0.08)
Log(EDU_{GDP})	0.31**	0.31***	0.31***
	(0.21)	(0.10)	(0.09)
Log(OPENNESS)	0.16**	0.11**	0.12***
	(0.06)	(0.04)	(0.05)
_cons	-15.31***	-12.60***	-12.70***
	(1.40)	(0.66)	(0.66)
Wald Chi square		2546.76***	2533.97***
Observations	252	252	252

* p<0.1, ** p<0.05, *** p<0.01 (Standard errors in parenthesis)

To check the robustness, Table 1.5 unveils the results of FGLS regressions using alternative variables. We use full time equivalent of R&D personal instead of R&D expenditures (columns 1 and 2); enrolment in tertiary education (SCHOOL) instead of Government expenditures on education (columns 3 and 4) and foreign direct investment (FDI) as another measure of the openness of countries (columns 5 and 6). Always with a view of avoiding the scale effect, we divided the two variables of R&D personal and FDI by the GDP, SCHOOL being already a percentage. Overall, results remain unchanged except for OPENNESS and EPS_{n}*onmarket* that become non-significant at 10%. The FDI_{GDP} does not have a significant impact on environmental innovation as well. By contrast $Personal_{GDP}$ has a strong significant effect (an increase of 1.44% is obtained following an increase of 1% in the R&D personal). Enrolment in tertiary education, even when it is hardly significant, has a too small impact close to zero.

Table 1.5: FGLS estimation results

	Log($ECOPAT_{GDP}$)$_{t+2}$					
	(1)	(2)	(3)	(4)	(5)	(6)
EPS	0.05*		0.12***		0.13***	
	(0.03)		(0.02)		(0.02)	
EPS_{market}		0.03*		0.08***		0.07***
		(0.02)		(0.01)		(0.01)
$EPS_{nonmarket}$		0.02		0.05***		0.05***
		(0.02)		(0.01)		(0.01)
Log($R\&D_{GDP}$)			1.21***	1.23***	1.16***	1.17***
			(0.08)	(0.08)	(0.07)	(0.07)
Log($Personal_{GDP}$)	1.44***	1.45***				
	(0.09)	(0.09)				
Log(DM_{PC})	1.20***	1.22***	0.84***	0.86***	0.84***	0.87***
	(0.10)	(0.10)	(0.08)	(0.08)	(0.07)	(0.07)
Log(EDU_{GDP})	0.31**	0.29**			0.33***	0.37***
	(0.12)	(0.12)			(0.09)	(0.09)
SCHOOL			0.003	0.003*		
			(0.00)	(0.00)		
Log(OPENNESS)	0.04	0.04	0.11***	0.13***		
	(0.09)	(0.09)	(0.04)	(0.04)		
FDI_{GDP}					-0.001	-0.001
					(0.00)	(0.00)
_cons	-17.71***	-17.76***	-12.10***	-12.32***	-12.30***	-12.56***
	(1.12)	(1.13)	(0.67)	(0.68)	(0.51)	(0.50)
Wald Chi square	2415.58	2497.86	2533.97***	2341.92***	3200.65***	3577.96
Observations	252	252	252	252	252	252

* p<0.1, ** p<0.05, *** p<0.01 (Standard errors in parenthesis)

1.5 Concluding remarks

This study contributes to eco-innovation determinants literature by exploring two aspects. Firstly, concerning the theoretical side, it matches together drivers from different economics fields to propose an analytical framework for further researches at a cross-country level. This first part highlights the singularity of eco-innovation with regard to standard innovation that consists in its favourable impact on the environment. This specific positive effect improves the social well-being and is particularly important due to the fact that the future life on earth depends on it. One central objective is then to make the private economic benefits of firms in line with this social benefit by promoting eco-innovations. In this context, economic literature emphasizes several drivers of environmental innovation that can be gathered into three groups "*technology-push*", "*demand-pull*" and "*institutional* determinants with the particular focus on the environmental *regulation*. Secondly, our study empirically investigates the eco-innovation determinants highlighted. To do so, we analysed panel data belonging to 12 European countries from 1990 to 2012 representing the three categories of determinants cited. The results confirm the theoretical findings. Indeed, the descriptive analysis of the data clearly shows the role of R&D and household demand, the two proxies of *technology push* and *demand pull*. An estimate using the FGLS confirms these results and shows that institutions do have a positive and significant role in eco-innovation as well. In addition to the empirical results, the most important is their implications for policymaker interventions. Globally the key recommendations of our work would be to promote and reinforce a European environmental plan by: 1) encouraging action in favour of the R&D and orienting it towards ecological solutions; 2) promoting the awareness activities in order to push the demand for green products; 3) implementing better regulations to be more effective; 4) creating a beneficial national environment.

For future research, it would be interesting to add other proxies representing the institutional performance of a country. They could be proxies or other variables on administrations, education system performance and so on. It would also be interesting to refine the data by studying data specific to eco-innovations and not broad ones such as environmental R&D, demand for green products and trends in environmental markets. Such research will be feasible in a few years through initiatives like the Eco-Innovation Observatory which is a European Union platform for the structured collection of eco-innovation information. Finally, and maybe the most important, is how to find a way to make all the above-cited recommendations possible.

Appendices

Table 6: Overview of empirical studies on the impact of environmental regulations on eco-innovations

References	**Level of analysis**	**Policy drivers and indicators**	**Dataset**	**Methodology**	**Main Results**
		Weak version of the Porter Hypothesis: Impact of Environmental regulations on innovation			
Arimura et al (2004)	Firms level	ER proxies: environmental conservation investment/ standards/ taxes/ R&D subsidies. Environmental innovation proxies: i) environmental R&D expenditures ii) Exhaust gas regulation	Japanese manufacturing facilities from Survey of Research and Developmentand Survey of Capital Investment.	Probit model with random effects / Random effect Tobit model	i) The ER stringency has a significantly positive impact on the probability to conduct an environmental R&D program; ii) Effect of flexible regulations was larger than direct regulations; iii) performance-based standards increase environmental R&D expenditure more than technology-based standards; iv) Input or emission taxes effects are not clear in the Japanese context.
Nelson et al (1993)		Two Environmental regulation (ER) proxies: i) air pollution cost ii) total pollution control costs per KW capacity	44 U.S. electric utilities over the 1969-1983 period	Panel data analysis: Three-stage least squares and linear fixed effects	i) ERs significantly increases age of capital; ii) Age of capital has no statistically-significant impact on emissions; iii) Air pollution regulation impacts emission levels.
Brunnermeier and Cohen (2003)	Industry Level	ER proxy: pollution and abatement control expenditures (PACE) and inspections Innovation proxy: environmentally-related patents	146 US manufacturing sectorData from 1983 to 1992	Panel data analysis: linear fixed effects / Poisson-Negative binomial model (fixed and random effects)	i) A small positive relationship of PACE on eco-patents ii) No impact of increased inspections and enforcements
Jaffe and Palmer (1997)		ER proxy: pollution abatement costs Innovation proxies: i) R&D expenditures; ii) patent applications	US manufacturing sectorData from 1973 to 1991	Panel data analysis: linear fixed effect model	i) Positive relation with R&D expenditures ii) No statistically significant effect on patent applications
De Vries and Withagen (2005)	Country level	ER proxy: i) international agreements (dummy variable), ii) Index of Environmental Sensitivity Performance (IESP) for acidification iii) Environmental stringency as a latent variable Innovation proxy: patents aiming at reducing SO2	14 OECD countries 1970-2000	Instrumental variable approach: fixed effects estimation	i) The two direct measures have no significant impact on innovation; ii) The third estimation reveals a positive impact of the regulation stringency on innovation.

Table 6 –

References	Level of analysis	Policy drivers and indicators	Dataset	Methodology	Main Results
Johnstone et al (2012)		ER proxy: Perceived policy stringency extracted from a survey. Innovation proxy: i) environmental patents; ii) General innovative capacity (Non-environmental patents/ GDP / R&D / Intellectual property rights index/ Net international trade)	Environmental patent data of 77 countries over the period 2001-2007	Panel data analysis: A subsequent two-stage model / Negative binomial model	- Higher environmental stringency positively affects environmental innovation
Lanjouw and Mody (1996)		ER proxy: - pollution abatement costs. Innovation proxy: share of environmental patents/total number of patents	Country data 1971-1988	Descriptive statistics (time series correlation)	i) Positive impact of the PACE in Germany, Japan and US; ii) In developing countries there is an increase of innovation imports for regulatory compliance accompanied by an increase of local innovations for adapting generic technologies to local conditions.
Narrow and Strong versions of the Porter Hypothesis: Impact of environmental regulations on Productivity					
Doran and Ryan (2012)	Firm level	ER proxies:i) Existing regulation, ii) Expected regulation, iii) Voluntary agreements, iv) Government Grants Productivity proxy : Turnover per worker	2,181 Irish firms Data from Irish Community Innovation Survey 2006-2008	Probit and OLS estimations	i) Regulations impact positively the eco-innovation; ii) Eco-innovation is found to be more important than non-eco-innovation in determining firm performance.
Gray and Shadbegian (2003)		ER proxies: Pollution and abatement control expenditures, ii) Input prices Firms business performance: i) Production function (labor, capital and materials inputs), ii) Growth rate	116 US paper mills, 1979-1990	Ordinary Least Squares(OLS) / Generalized Method of Moments model (GMM)	i) Significant reduction in productivity associated with abatement efforts particularly in integrated paper mills; ii) Older plants appear to have lower productivity but are less sensitive to abatement costs; iii) Renovated plants are less sensitive to abatement costs.
Costantini and Mazzanti (2012)	Industry level	ER proxies: i) Energy and environmental tax revenues, ii) Private compulsory and voluntary actions: PACE, Environmental Management System (EMS); Performance proxy: (green) export flows	Exporting countries : All EU15 members where Belgium and Luxembourg are merged / 145 importing countries / Time period: 1996-2007	Dynamic panel gravity models	Test “narrow” and “strong” version: Strict environmental regulation may stimulate green innovation and increase competitiveness in exports of environmental technologies.

Table 6 –

References	Level of analysis	Policy drivers and indicators	Dataset	Methodology	Main Results
Franco and Marin (2015)		ER proxy: Environmental taxes Innovation proxy: Patents Performance proxy: Productivity	Panel data for 13 manufacturing sectors for 7 European countries, 2001-2007		The strongest effects on the "weak" and "strong" version of PH come from the downstream sectorsThe strongest impact on productivity come from the direct effectThe indirect effect, i.e. the effect of the innovations on productivity is not significant
Lanoie et al (2008)		ER proxy: i) Changes in the ratio of the value of investment in pollution control equipment to the total cost, ii) OSH (regulation onsafety in the workplace index) Productivity: Total factor productivity (TFP) growth	17 Quebec manufacturing industries 1985-1994	Generalized least-squares (GLS) procedure	i) Contemporaneous effect of environmental regulation on productivity is negative, but positive impact is detected when using lagged variables of environmental regulation; ii) ERs have a significant positive impact on productivity growth rate, especially in the sectors highly exposed to outside competition.
Lanoie et al (2011)		ER proxies : stringency/standards/taxes (dummy variables) Innovation proxy: Environmental R&D (dummy variable); Environmental performance index; Commercial performance (dummy variable)	Survey of over 4000 manufacturing facilities in 7 OECD countries from the OECD survey on environmental practices.	Descriptive statistics	i) Test the three versions of PH; ii) Strong positive impact of ER on R&D ("weak version"); iii) Greater incentive of flexible regulations than prescriptive ones on innovations using the impact on environmental results ("narrow version"); iv) No impact of ER on commercial performance ("strong version").
Rubashkina et al (2015)		ER proxy: PACE Innovation proxy: Patents, Competitiveness proxy: Total factor productivity (TFP)	Panel data on the manufacturing sectors of 17 European countries, 1997-2009	Two-Stage Least Squares regression (2SLS) / Instrumental variable-GMM (IV-GMM)	Test the "weak" version of PH is verified but not the "strong" one
Albrizio et al (2014)	Cross-Country	ER proxy: Environmental Policy Stringency (EPS) index, Productivity proxy: Estimated multi-factor productivity function for each country	19 OECD countries over the 1990-2010 period	Panel data analysis: linear fixed effect	At the macro level, a negative effect on productivity growth is found one year ahead of the policy change. This negative "announcement effect" is offset within three years after the implementation.

Table 6 –

References	Level of analysis	Policy drivers and indicators	Dataset	Methodology	Main Results
De Santis and Jona-Lasinio (2015)		ER proxies: i) EPS index, ii) CO_2 emissions as a difference with respect to the 2020 target iii) Environnemental taxes iv) The introduction of the European Emission Trading System v) The ratification of the Kyoto agreement. Innovation proxies:i) ICT, ii) R&D. Productivity proxy: Labour productivity	11 European economies in 1995-2008	A difference in difference approach	i) the "narrow" version of PH is verified; ii) Market based environmental stringency measures stimulate innovations and productivity better than non-market based.
Morales et al (2016)		ER proxy: EPS index Innovation proxy: i) R&D, ii) Patents applications. Production proxy: Total factor productivity	14 OECD countries over the period 1990-2011	Panel models: LS model estimation with country-sector and time fixed effects and Newey-West correction / Panel-quantile regression with time fixed effects	i) Positive impact of ER stringency on innovation and productivity ("weak" and "strong" versions of the PH); ii) Quantile regressions show that ER has greater impact on the lower quantile of R&D and the highest quantiles of Patents and TFP distribution

Table 7: Articles testing the trichotomy of Rennings

References	**Dataset**	**Supply push and firms specific factors determinants**	**Demand pull determinants**	**Reugalatory push-pull determinants**	**Methodology**	**Mains Resultats**
Cleff and Rennings (1999)	Mannheim Innovation Panel (1996), and a subsequent telephone survey of environmental innovators	i) Cost saving; ii) Size; iii) geographical origin	i) Market share, ii) Customer demand/Image	i) Existing (expected) regulation; ii) Soft regulations (e.g. labels, eco-audits).	Multinomial logit models	i) Regulation : + (process innovations); ii) soft regulation: + (pioneers); iii) Hard regulations: + (diffusion); iv) strategic market goals : + (product technologies)
Cuerva et al (2014)	Spain, Agri-foods SMEs (2010)	i) R&D; ii) Human Capital; iii) Quality management; iv) Financial constraints	i) CSR; ii) Label, geographic indication, iii) Anticipated demand iv) Product diffrenciation	Subsidies	A bivariate probit regression	i)Product differentiation:+; ii) Quality management: +; iii) Subsidies : 0
Demirel Kesidou (2011)	UK firms DEFRA Government Survey of Environmental Protection Expenditure by Industry, 2005 and 2006	firm specific factors (cost savings/EMS /ISO14001/ employees/ turnover / productivity. . .)		policy tools (environmental regulation compliance / environmental taxes)	Tobit model	+Determinants' effects differ according to the type of innovation
Doran and Ryan (2012)	2,181 Irish firms, Data from Irish Community Innovation Survey 2006-2008	i) Intramural / extramural R&D; ii) Firm Specific Factors (Employment, capital, Irish owned firms); iii) Sectors	i) consumer expectations; ii) Firms collaboration in the development of new innovations (with suppliers, customers, consultants, competitors,universities and public research institutes)[22]	i) Existing Regulation, ii) Expected regulation Regulation, iii) voluntary agreements, iv) Government Grants	Probit estimation	i) Regulation : +; ii) Customer perception : +; iii) Collaboration with suppliers and consultants:+; iv) Other collaborations: 0; v) Intramural R&D: +; vi) Extramural R&D: 0; vii) Size : +; viii) Irish owned firms:0; ix) Sectors: 0
Frondel et al (2008)	OECD countries (Canada, France, Germany, Hungary, Japan, Norway and USA)	i) R&D investment, ii) interest groups and Organizations (internal forces, Industrial associations and labour unions. . .), iii) Management tools, iv) Facility Characteristics (size, turnover, environmental impacts, green employment, v) Industry dummies	i) Incidents, ii) Corporate Image, iii) Cost Savings, iv) interest groups andOrganizations (Green organisations, Custumers, buyers and Suppliers, banks. . .)	Policy Stringency (dummy): i) Regulatory Measures ((input bans, standards), ii) Market Instruments, iii) Information (for consumers and buyers), iv) Voluntary Measures, v) Subsidies	Multinomial logit models / a binary probit model	i) Regulation: + (end-of-pipe technologies); ii) Cost savings, management system : + (clean technologies)
Green et al (1994)	UK: a 1993 questionnaire survey of innovating activities (R&D and development of new eco-products and processes) of firms in response to environmental pressure	Inputs: i) cost savings, ii) availability of new technologies, iii) Change in supplied components	i) Retailer / wholesaler pressure, ii) Prospect of expanding market share, iii) Rival eco-products / processes appearing, iv) Rival eco-products/processes feared, v) expected customer demand	i) Existing UK/EC regulations; ii) anticipated UK/EC regulations	Case studies	i) Studied drivers: +; ii) Other drivers have to be added (from sociology of technology and evolutionary theory)

[22] These determinants can be considered as supply-pull one (Pereira and Vence, 2012)

Table 7 –

References	Dataset	Supply push and firms specific factors determinants	Demand pull determinants	Reugalatory push-pull determinants	Methodology	Mains Resultats
Hammar and Lofgren (2010)	Four major sectors in Sweden between 2000 and 2003	i) Internal learning by doing and knowledge (R&D investments), ii) Firms' size (revenues, energy price)			Random effects logit model	Determinants' effects differ according to the type of innovation (end of pipe / clean technology)
Horbach (2008)	German Industry (2001-2004)German firms	i) R&D activity, ii) employees' qualifications, iii) cooperation, iv) sector/region/size/age	i) Expected customer demand ii) Expected employment level	i) Subsidies, ii) Compliance with (future) environmental regulation	Multinomial logit model	i) R&D: +, ii) Size : 0 and +, iii) Sectors: - for some / 0 for others, iv) Demand: +, v) Compliance with regulation: +, vi) Subsidies: +
Horbach et al(2013)	4th CIS 2002-2004 for France and Germany, Industry	i) Cost reduction, ii) Production flexibility	i) Increasing market share, ii) Increasing product quality	i) Perception of regulationsor standards' severity, ii) Subsidies, iii) Abatement costs	A bivariate probit regression	i) Regulation: +, ii) Cost reduction: +, iii) Production flexibility: +, iv) Market pull determinants : + in Germany, 0 in France
Kammerer (2009)	German electronics and electrical appliances industry	i) R&D employees, ii) Green capabilities	Customers benefits/satisfaction	Compliance with environmental regulation	Logit regression	i) Demand pull: +, ii) Regulation : +, iii) R&D: 0
Mazzanti and Zoboli (2005)	Italian firms in the manufacturing sector	i) Environmental R&D, ii) Environmental investment, iii) Environmenatl costs, iv) Structural characteristics (share of revenue in international markets, the share of finalmarket production, sector of activity, membership to nationalor international industrial groups), v) Past firms' performances (value added perEmployee, gross profit/turnover)…		i) Compliance with (future) environmental regulation, ii) environmental voluntary auditing schemes (EMS or ISO)	OLS / Probit / Tobit / two-stage regressions	i) Supply push: +, ii) Regulation: +
Rave et al (2011)	German firms in late 2007 and 2009	i) Size, ii) Age, iii) cost saving, iv) Network activities	i) Social pressure or image, ii) Demand from and image vis-a-vis customers, iii) Maintenance or enlargement of current/new markets	i) Subsidies, ii) predictable and strict environmental policy	Probit / Random-effects probit / Negative binomial / Ordered probit	i) cost saving: +, ii) Regulation: +, iii) creation of new markets:+; (Determinants' effects differ according to the type of innovation)
Rehfeld et al (2007)	German case studies	i) R&D activities, ii) Specific company characteristics (ISO9001, Size, age)	i) Customers benefits/satisfaction, ii) Exportation	i) Compliance with (future) environmental regulation, ii) Soft regulation (EMS, waste disposal, life cycle assessment activities environmental labelling)	Binary and multinomial logit models	+

Table 7 –

References	Dataset	Supply push and firms specific factors determinants	Demand pull determinants	Reugalatory push-pull determinants	Methodology	Mains Resultats
Triguero et al (2013)	27 EU countries, all sector SMEs (2011)	i) Technological and organizational improvements, ii) Collaboration with research institutes and universities, iii) Access to information from external technological services, iv) Input price, v) Energy price	i) Consolidation orincrease in market share, ii) Anticipating demand of green product	i) Existant regulation, ii) Anticipation of future regulation, iii) Subsidies	a Trivariate probit model	i) Demand-pull determinants: + on product eco-innovations, ii) The Technology-push determinants: + on process eco-innovations, iii) Regulatory determinants: + on organizational eco-innovations
Ziegler (2005)	Germany, manufacturing industry (2003-2005)	i) R&D, ii) Number of employees	Competitive advantage related to: i) Environment, ii) Price, iii) Quality, iv) Consumers	Binary variable: localization in Western Germany	Multinomial logit and probit models	i) R&D : +, ii) Number of establishments : 0, iii) Market pull: little effect

Table 8: Some empirical articles on the drivers of innovation at a country level

References	Level of analysis	Policy drivers and indicators	Methodology	Main Results
Bayar (2015)	Eurozone countries during the period 1999-2012	Dependent variable: Patents; Independent variables: i) R&D expenditures, ii) Economic growth: Real GDP per capita growth (annual %), iii) Financial development: domestic credit to private sector, iv) Inflation: Consumer price index, v) foreign direct investment inflows, vi) Gross domestic savings, vii) High technology exports	Poisson regression,negative binomial regression	Economic growth, financial development, savings, R&D expenditures and high technology exports had positive impact on technological progress.
Coe et al (2009)	24 countries over 1971-2004	Dependent variable: Total factor productivity (real value added in business sector, capital stock, labour input); Independent variables: i) R&D: business sector R&D expenditure, R&D capital stocks in the business sector, foreign R&D capital, ii) Human capital : average years of schooling, iii) Openness : ratio of total imports of goods and services to GDP, iv) institutional variables : legal origin and patent protection	Panel cointegration estimation techniques	Institutional differences are important determinants of total factor productivity and that they impact the degree of R&D spillovers

Table 8 –

References	Level of analysis	Policy drivers and indicators	Methodology	Main Results
Eyraud et al (2011)	35 advanced and emerging countries with annual data over 2000-2010	Dependent variable: Renewable investment; Independent variables: R&D, GDP (GDP/capita), population, inflation, International gasoline price, Crude oil price, Domestic gasoline price, wage, unit labour cost, profit, Cost of starting a business, Interest rates, tax on business, fossil fuel use, green parties, domestic credit, bank capital, energy dependency, carbon emissions, policy support for renewable electricity generation (Feed-In-Tariffs , Renewable Portfolio Standards), Biofuel mandates, Carbon pricing schemes, Spending on tertiary Education, Enrolment in tertiary education, coal price	Fixed-effect estimation	i) Economic growth, low interest rates, high fuel prices, introduction of carbon pricing schemes, "feed-in-tariffs": +; ii) biofuel support:0

Table 8 –

References	Level of analysis	Policy drivers and indicators	Methodology	Main Results
Furman et al (2002)	17 OECD countries over 1973-1995	Dependent variable: patents / patents per million population; Independent variables: i) Quality of the common innovation infrastructure : GDP per capita, stocks of patents, population, employed scientists and engineers, R&D expenditures, openness, protection for intellectual property, share GDP spent on higher education, antitrust policies; ii) Cluster-specific innovation environment: R&D funded by private industry (%), Ellison-Glaeser concentration Index; iii) Quality of linkages: R&D performed by universities (%), Strenght of Venture capital markets	OLS Fixed effects models	The paper introduces and testes the novel framework based on the concept of national innovative capacity which investigates the overall sources of innovation systems at the country level.
Guloglu et al (2012)	G7 countries 1991-2009	Dependent variable: Patents; Independent variables: royalty payments, Gross Domestic Expenditures on R&D, Foreign Direct Investment, high-technology exports, openness to trade, rate of interest	Poisson regression, Negative binomial regression techniques	i) rate of interest: -; ii)investments in the R&D sector, high-technology exports, net FDI inflows: +; iii) openness to trade ratio : 0

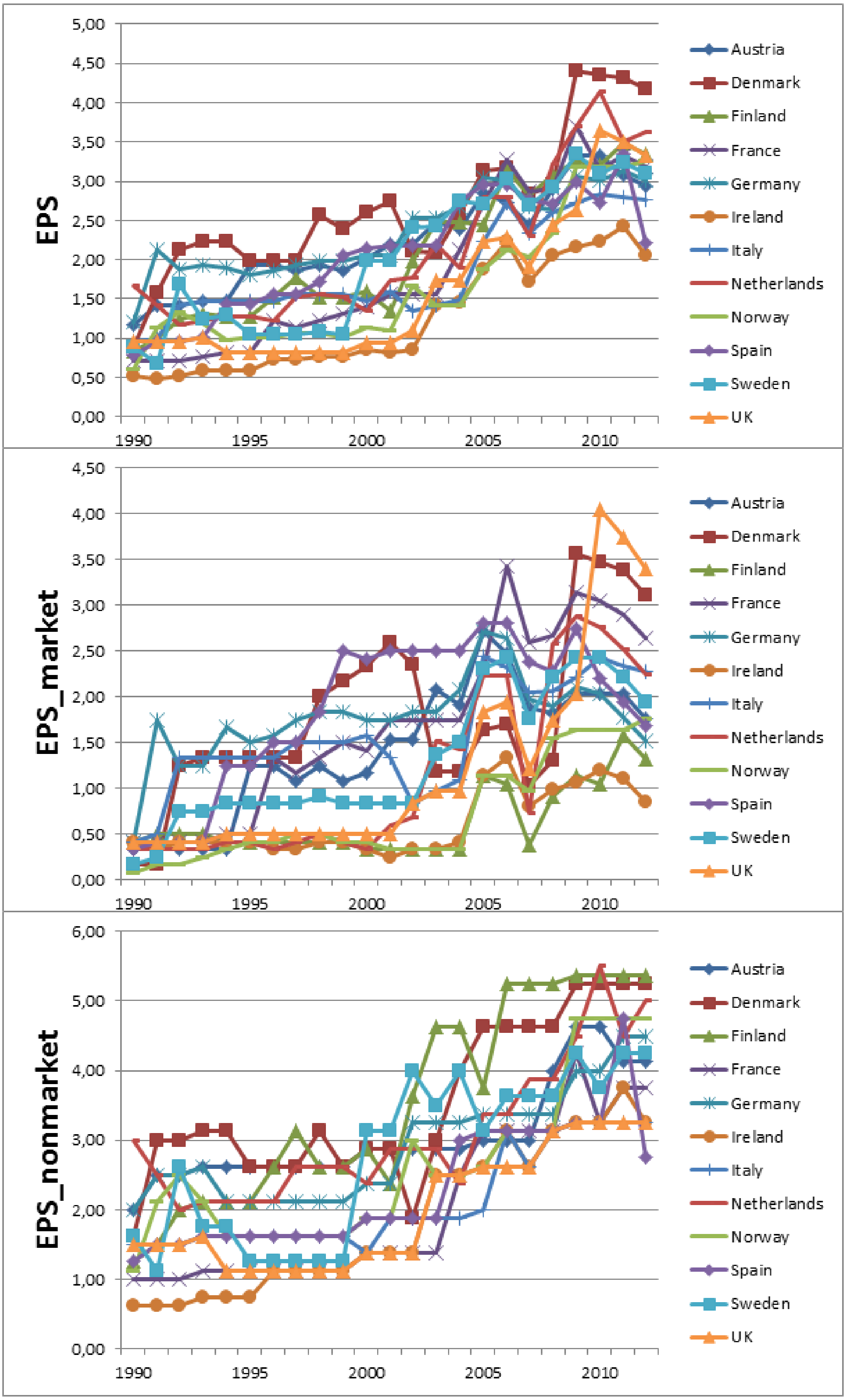
Table 8 –

References	Level of analysis	Policy drivers and indicators	Methodology	Main Results
Huňady and Orviská (2014)	26 European countries1999-2011	Dependent variable: i) Innovation : summary innovation index/ index of innovation growth; ii) Economic growth : annual GDP change; Independent variables: R&D expenditure, GDP per capita, FDI, openness of trade, effective average corporate tax rate, unemployment, public debt, average of statutory corporate tax rates in neighboring countries, corruption	Correlation analysis and Fixed effect model	i) Positive correlation between innovation and GDP per capita, ii) R&D impact positively innovation, iii) All the variables have the expected impact on GDP growth.
Khan and Roy (2011)	5 OECD countries and the BRICS 1997-2010	Dependent variable: Patents, Independent variables: R&D expenditures, trade openness, enrolment in tertiary education, internet access, ethnic diversity Index, per capita power consumption, fiscal variables (Maximum Corporate Income Tax Rate, Maximum Personal Income Tax Rate)	Random and fixed effect regressions	Focusing more on BRICS: i) R&D's impact is lower for BRICS than OECD, ii) Education , openness: +, iii) Internet access, ethnic diversity Index : 0
Krammer (2009)	16 Eastern European transition countries1991-2007	Dependent variable:Patents Independent variables: Patent stocks, R&D expenditures/number of researchers, Foreign direct investment, Trade intensity, Intellectual property rights index, Cost of doing business, Industrial distortion index, Education expenditure, Population	FGLS / OLS with Newey-West standard errors / Poisson regression / Negative binomial maximum likelihood / two-step negative binomial quasi-generalized maximum likelihood estimator	i) Patent stocks and R&D :+; ii) Policy measures: +, iii) Transitional downturn and industrial restructuring: -; iv) Globalization : +

Table 8 –

References	Level of analysis	Policy drivers and indicators	Methodology	Main Results
Ulku (2004)	20 OECD and 10 Non-OECD countries for the period 1981–1997	Dependent variable: Innovation: patents applications; Independent variables: GDP, investment, secondary school enrolments employment, openness, expropriation risk index, import/trade in manufacturing	Fixed Effects / GMM / OLS regressions	i) R&D stock on innovation: + on OECD countries 0 Non-OECD countries; ii) Innovation and GDP per capita : +
Varsakelis (2006)	29 developed and developing countries for 1995-2000	Dependent variable: Innovation: patents; Independent variables: i) Education system: scores in mathematics and natural sciences, numbers of students enrolled in higher education with science orientation ii) Research activity: R&D expenditure intensity; iii) Institutional variables: political rights, civil liberties, corruption perception index, press freedom	Random effect panel estimation	The quality of education and governmental institution impact the innovation activity

.1 Evolution of the environmental policy stringency



.2 R&D expenditures

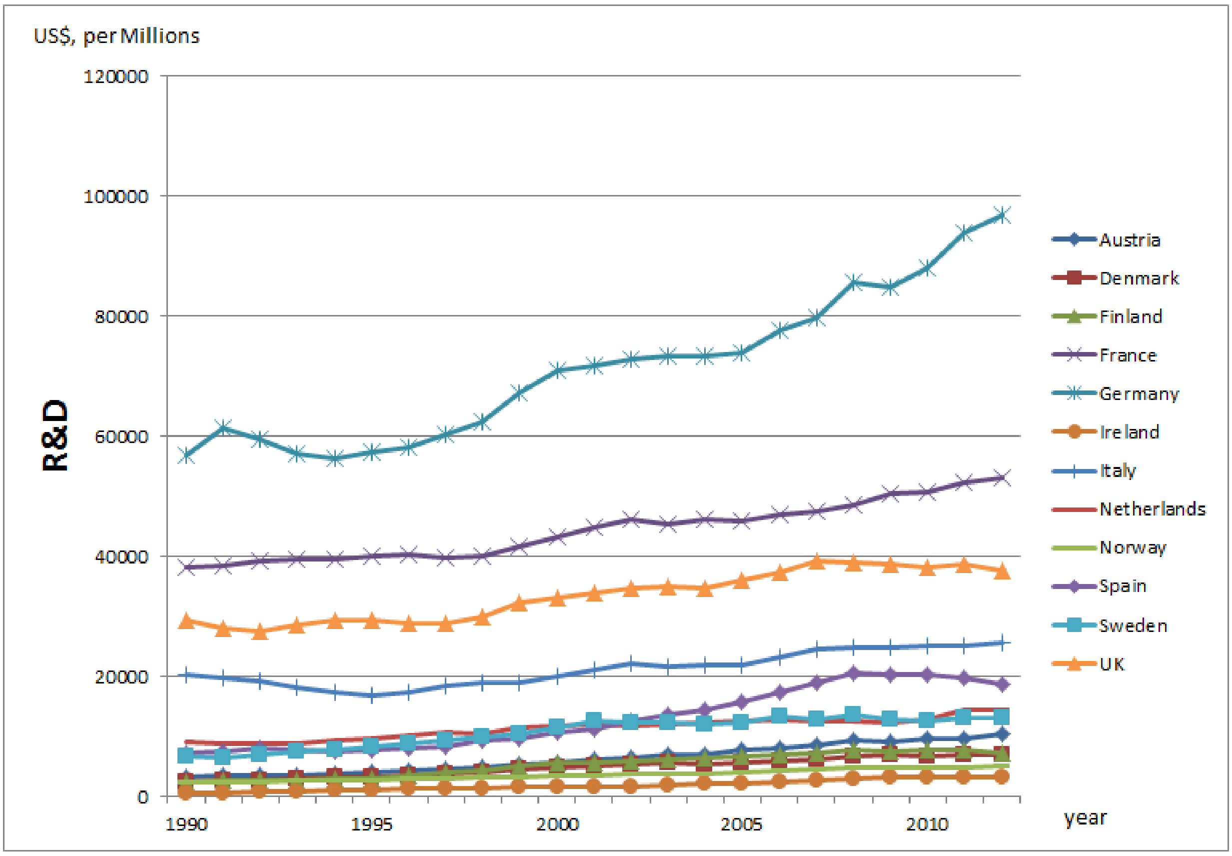


Figure 13: R&D expenditures

.3 Evolution of Government expenditures on education (as% of GDP)

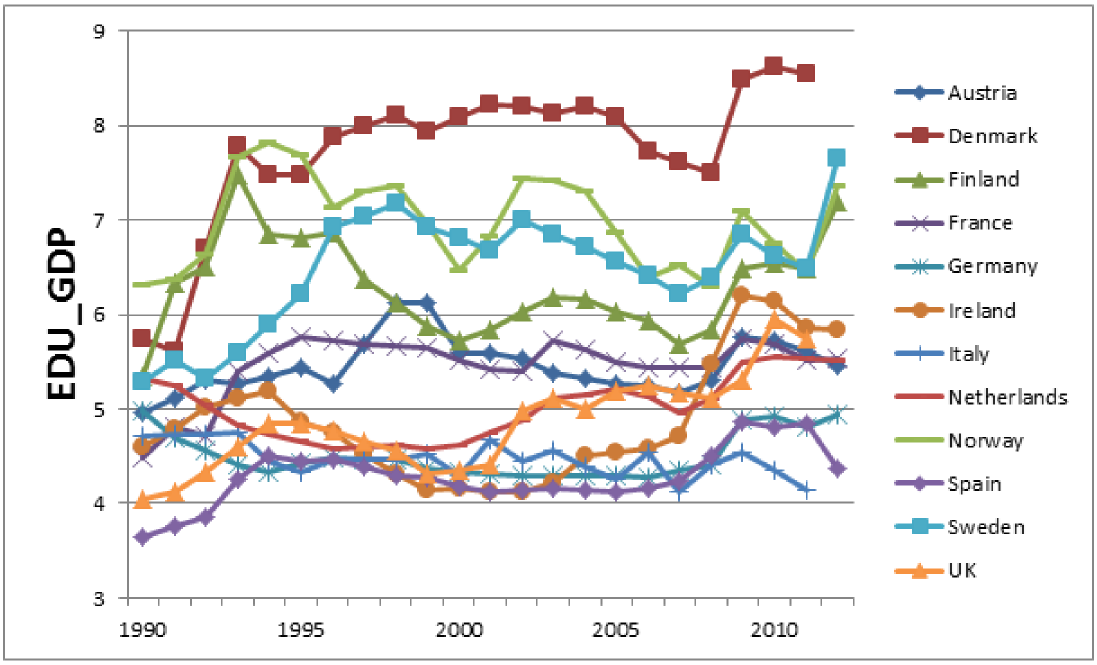


Figure 14: Government expenditures on education (as% of GDP)

Bibliography

Afif, Mourad, “Incitation à l’adoption de technologies propres,” Technical Report, Bureau d’Economie Théorique et Appliquée, UDS, Strasbourg 2012.

_ **and Sandrine Spaeter**, “Contrôle des émissions polluantes et combinaison optimale transferts/permis,” Technical Report, Bureau d’Economie Théorique et Appliquée, UDS, Strasbourg 2009.

Albrizio, Silvia, Tomasz Koźluk, and Vera Zipperer, “Empirical evidence on the effects of environmental policy stringency on productivity growth,” 2014.

Ambec, Stefan and Paul Lanoie, “Laboratoire d’Economie Appliquée de Grenoble,” 2007.

Baltagi, Badi, *Econometric analysis of panel data*, John Wiley & Sons, 2008.

Barsoumian, Sarine, Astrid Severin, and Titus van der Spek, “Eco-innovation and national cluster policies in Europe,” *A Qualitative Review. Europe INNOVA, European Cluster Observatory*, 2011.

Baumol, William J, *The free-market innovation machine: Analyzing the growth miracle of capitalism*, Princeton university press, 2002.

Bayar, Yilmaz, “Macroeconomic Determinants of Technological Progress in Major Eurozone Member Countries,” *International Journal of Economic Practices and Theories*, 2015, *5* (5), 420–427.

Beck, Nathaniel and Jonathan N Katz, “What to do (and not to do) with time-series cross-section data,” *American political science review*, 1995, *89* (03), 634–647.

Beers, Cees Van and Jeroen CJM Van Den Bergh, “An empirical multi-country analysis of the impact of environmental regulations on foreign trade flows,” *Kyklos*, 1997, *50* (1), 29–46.

Blind, Knut, “The influence of regulations on innovation: A quantitative assessment for OECD countries,” *Research Policy*, 2012, *41* (2), 391–400.

Botta, Enrico and Tomasz Koźluk, “Measuring Environmental Policy Stringency in OECD Countries,” 2014.

Breusch, Trevor S and Adrian R Pagan, “A simple test for heteroscedasticity and random coefficient variation,” *Econometrica: Journal of the Econometric Society*, 1979, pp. 1287–1294.

Brouillat, Eric and Vanessa Oltra, "Extended producer responsibility instruments and innovation in eco-design: An exploration through a simulation model," *Ecological Economics*, 2012, *83*, 236–245.

Brunel, Claire and Arik Levinson, "Measuring environmental regulatory stringency," 2013.

Brunnermeier, Smita B and Mark A Cohen, "Determinants of environmental innovation in US manufacturing industries," *Journal of environmental economics and management*, 2003, *45* (2), 278–293.

Bush, Vannevar, "Science: The endless frontier," *Transactions of the Kansas Academy of Science (1903-)*, 1945, *48* (3), 231–264.

Cleff, Thomas and Klaus Rennings, "Determinants of environmental product and process innovation," *European environment*, 1999, *9* (5), 191–201.

Coe, David T and Elhanan Helpman, "International r&d spillovers," *European economic review*, 1995, *39* (5), 859–887.

_ , _ , and Alexander W Hoffmaister, "International R&D spillovers and institutions," *European Economic Review*, 2009, *53* (7), 723–741.

Cohen, Wesley M, Richard R Nelson, and John P Walsh, "Protecting their intellectual assets: Appropriability conditions and why US manufacturing firms patent (or not)," Technical Report, National Bureau of Economic Research 2000.

Crespi, Francesco, Claudia Ghisetti, Francesco Quatraro et al., "Taxonomy of implemented policy instruments to foster the production of green technologies and improve environmental and economic performance," *WWWforEurope MS216 draft paper.(2015 forthcoming)*, 2015.

Cuerva, Maria C, Ángela Triguero-Cano, and David Córcoles, "Drivers of green and non-green innovation: empirical evidence in Low-Tech SMEs," *Journal of Cleaner Production*, 2014, *68*, 104–113.

Demirel, Pelin and Effie Kesidou, "Stimulating different types of eco-innovation in the UK: Government policies and firm motivations," *Ecological Economics*, 2011, *70* (8), 1546–1557.

Doran, Justin and Geraldine Ryan, "Regulation and firm perception, eco-innovation and firm performance," *European Journal of Innovation Management*, 2012, *15* (4), 421–441.

Dosi, Giovanni and Richard R Nelson, "An introduction to evolutionary theories in economics," *Journal of evolutionary economics*, 1994, *4* (3), 153–172.

Edquist, Charles, *Systems of innovation: technologies, institutions, and organizations*, Psychology Press, 1997.

_ , "The Systems of Innovation Approach and Innovation Policy: An account of the state of the art," in "DRUID Conference, Aalborg" 2001, pp. 12–15.

Eyraud, Luc, Abdoul Aziz Wane, Changchang Zhang, and Benedict J Clements, "Who's going green and why? Trends and determinants of green investment," *IMF Working Papers*, 2011, pp. 1–38.

Fagerberg, Jan et al., "Innovation policy, national innovation systems and economic performance: In search of a useful theoretical framework," Technical Report, Centre for Technology, Innovation and Culture, University of Oslo 2015.

Fischer, Carolyn, Ian WH Parry, and William A Pizer, "Instrument choice for environmental protection when technological innovation is endogenous," *Journal of Environmental Economics and Management*, 2003, *45* (3), 523–545.

Franco, Chiara and Giovanni Marin, "The Effect of Within-Sector, Upstream and Downstream Environmental Taxes on Innovation and Productivity," *Environmental and Resource Economics*, 2015, pp. 1–31.

Freeman, Chris, "The 'National System of Innovation'in historical perspective," *Cambridge Journal of economics*, 1995, *19* (1), 5–24.

Freeman, Christopher, "The economics of industrial innovation," *University of Illinois at Urbana-Champaign's Academy for Entrepreneurial Leadership Historical Research Reference in Entrepreneurship*, 1982.

_ , *Technology policy and economic performance*, Pinter Publishers Great Britain, 1989.

_ **and Luc Soete**, "Developing science, technology and innovation indicators: What we can learn from the past," *Research policy*, 2009, *38* (4), 583–589.

Frondel, Manuel, Jens Horbach, and Klaus Rennings, "End-of-Pipe or Cleaner Production? An Empirical Comparison of Environmental Innovation Decisions Across OECD Countries," *SSRN Working Paper Series*, 2008.

Furman, Jeffrey L and Richard Hayes, "Catching up or standing still?: National innovative productivity among 'follower'countries, 1978–1999," *Research Policy*, 2004, *33* (9), 1329–1354.

_ **, Michael E Porter, and Scott Stern**, "The determinants of national innovative capacity," *Research policy*, 2002, *31* (6), 899–933.

Goulder, Lawrence H and Ian WH Parry, "Instrument choice in environmental policy," *Review of environmental economics and policy*, 2008, *2* (2), 152–174.

Green, Kenneth, Andrew McMeekin, and Alan Irwin, "Technological trajectories and R&D for environmental innovation in UK firms," *Futures*, 1994, *26* (10), 1047–1059.

Griliches, Zvi, "Hybrid corn: An exploration in the economics of technological change," *Econometrica, Journal of the Econometric Society*, 1957, pp. 501–522.

_ , "Patent statistics as economic indicators: a survey," Technical Report, National Bureau of Economic Research 1990.

Guloglu, Bulent, R Baris Tekin, and Ercan Saridogan, "Economic determinants of technological progress in G7 countries: A re-examination," *Economics Letters*, 2012, *116* (3), 604–608.

Hammar, Henrik and AAsa Löfgren, "Explaining adoption of end of pipe solutions and clean technologies—determinants of firms' investments for reducing emissions to air in four sectors in Sweden," *Energy Policy*, 2010, *38* (7), 3644–3651.

Haščič, Ivan and Mauro Migotto, "Measuring environmental innovation using patent data," 2015.

Hemmelskamp, Jens, "Environmental policy instruments and their effects on innovation," *European Planning Studies*, 1997, *5* (2), 177–194.

Hicks, John, *Theory of wages*, London, Macmillanr, 1932.

Hippel, Eric Von, "Lead users: a source of novel product concepts," *Management science*, 1986, *32* (7), 791–805.

_ , "Open source shows the way: Innovation by and for users–no manufacturer required," *Sloan Management Review*, 2001, *42* (4), 82–86.

_ , "Democratizing innovation: The evolving phenomenon of user innovation," *Journal für Betriebswirtschaft*, 2005, *55* (1), 63–78.

Horbach, Jens, "Determinants of environmental innovation—new evidence from German panel data sources," *Research policy*, 2008, *37* (1), 163–173.

_ , Vanessa Oltra, and Jean Belin, "Determinants and specificities of eco-innovations compared to other innovations—an econometric analysis for the French and German industry based on the community innovation survey," *Industry and Innovation*, 2013, *20* (6), 523–543.

Hu, Mei-Chih and John A Mathews, "National innovative capacity in East Asia," *Research Policy*, 2005, *34* (9), 1322–1349.

Huňady, Ján and Marta Orviská, "The impact of research and development expenditures on innovation performance and economic growth of the country—the empirical evidence," in "CBU International Conference Proceedings," Vol. 2 2014, pp. 119–125.

Jaffe, Adam B and Karen Palmer, "Environmental regulation and innovation: a panel data study," *Review of economics and statistics*, 1997, *79* (4), 610–619.

_ , Richard G Newell, and Robert N Stavins, "Environmental policy and technological change," *Environmental and resource economics*, 2002, *22* (1-2), 41–70.

Jang, Eun Kyung, Mi Sun Park, Tae Woo Roh, and Ki Joo Han, "Policy instruments for eco-innovation in Asian countries," *Sustainability*, 2015, *7* (9), 12586–12614.

Johnstone, Nick, Ivan Haščič, Julie Poirier, Marion Hemar, and Christian Michel, "Environmental policy stringency and technological innovation: evidence from survey data and patent counts," *Applied Economics*, 2012, *44* (17), 2157–2170.

Jones, Charles I, "R & D-based models of economic growth," *Journal of political Economy*, 1995, pp. 759–784.

Kammerer, Daniel, "The effects of customer benefit and regulation on environmental product innovation.: Empirical evidence from appliance manufacturers in Germany," *Ecological Economics*, 2009, *68* (8), 2285–2295.

Kemp, Rene and Peter Pearson, *Measuring eco-innovation*, United Nations University Maastricht, 2008.

Khan, Abdullah M and Priya A Roy, "Globalization and the determinants of innovation in BRICS versus OECD economies: A macroeconomic study," *Journal of Emerging Knowledge in Emerging Markets*, 2011, *3*, 28–45.

Klewitz, Johanna, Anica Zeyen, and Erik G Hansen, "Intermediaries driving eco-innovation in SMEs: a qualitative investigation," *European Journal of Innovation Management*, 2012, *15* (4), 442–467.

Koźluk, Tomasz and Vera Zipperer, "Environmental policies and productivity growth," *OECD Journal: Economic Studies*, 2015, *2014* (1), 155–185.

Krammer, Sorin MS, "Drivers of national innovation in transition: Evidence from a panel of Eastern European countries," *Research Policy*, 2009, *38* (5), 845–860.

Lanoie, Paul, Jérémy Laurent-Lucchetti, Nick Johnstone, and Stefan Ambec, "Environmental policy, innovation and performance: new insights on the Porter hypothesis," *Journal of Economics & Management Strategy*, 2011, *20* (3), 803–842.

_ , Michel Patry, and Richard Lajeunesse, "Environmental regulation and productivity: testing the porter hypothesis," *Journal of Productivity Analysis*, 2008, *30* (2), 121–128.

Leone, Fabio and Jens Hemmelskamp, "The Impact of EU-Regulation on Innovation of European Industry," *Sevilla (Institute for Prospective Technological Studies, IPTS)*, 1998.

Levinson, Arik, "State taxes and interstate hazardous waste shipments," *The American Economic Review*, 1999, *89* (3), 666–677.

Low, Patrick and Alexander Yeats, "Do" dirty" industries migrate?.," *World Bank Discussion Papers[WORLD BANK DISCUSSION PAPER.]. 1992.*, 1992.

Lucas, Robert E, "On the mechanics of economic development," *Journal of monetary economics*, 1988, *22* (1), 3–42.

Lundvall, Bengt-Åke, *Product innovation and user-producer interaction*, Aalborg Universitetsforlag, 1985.

_ , "Innovation as an interactive process," in "Technical change and economic theory" 1988.

Lundvall, Bengt-Ake, "The social dimension of the learning economy," *SSRN Working Paper Series*, 1998.

Lundvall, Bengt-Åke, "The learning economy: challenges to economic theory and policy," *A Modern Reader in Institutional and Evolutionary Economics: Key Concepts. Cheltenham: Edward Elgar*, 2002b, pp. 26–47.

— , “National innovation systems—analytical concept and development tool,” *Industry and innovation*, 2007, *14* (1), 95–119.

— , *National systems of innovation: Toward a theory of innovation and interactive learning*, Vol. 2, Anthem Press, 2010.

Lundvall, Bengt-Äke and Björn Johnson, “The learning economy,” *Journal of industry studies*, 1994, *1* (2), 23–42.

Lundvall, Bengt-Åke, Björn Johnson, Esben Sloth Andersen, and Bent Dalum, “National systems of production, innovation and competence building,” *Research policy*, 2002, *31* (2), 213–231.

Malueg, David A, “Emission credit trading and the incentive to adopt new pollution abatement technology,” *Journal of Environmental Economics and Management*, 1989, *16* (1), 52–57.

Martinez, Catalina, “Insight into different types of patent families,” 2010.

Mazzanti, Massimiliano and Roberto Zoboli, “The drivers of environmental innovation in local manufacturing systems,” *Economia politica*, 2005, *22* (3), 399–438.

Metcalfe, Stan, “The economic foundations of technology policy: equilibrium and evolutionary perspectives,” *Handbook of the economics of innovation and technological change*, 1995, *446.*

Miettinen, Reijo, *National innovation system: scientific concept or political rhetoric*, Edita, 2002.

Morales-Lage, Rafael, Aurelia Bengochea Morancho, and Inmaculada Martínez-Zarzoso, “Does environmental policy stringency foster innovation and productivity in OECD countries?,” *Available at SSRN 2764834*, 2016.

Mowery, David and Nathan Rosenberg, “The influence of market demand upon innovation: a critical review of some recent empirical studies,” *Research policy*, 1979, *8* (2), 102–153.

Mulder, Peter, Henri LF De Groot, and Marjan W Hofkes, “Economic growth and technological change: A comparison of insights from a neo-classical and an evolutionary perspective,” *Technological Forecasting and Social Change*, 2001, *68* (2), 151–171.

Nelson, Richard R and Sidney G Winter, “Evolutionary theorizing in economics,” *The journal of economic perspectives*, 2002, *16* (2), 23–46.

— **and Sidney Winter**, “An evolution theory of economic change,” *Cambridge, MA: Belknap*, 1982.

North, Douglass C, *Institutions, institutional change and economic performance*, Cambridge university press, 1990.

North, Douglass Cecil, *The Role of Institutions in Economic Development: Gunnar Myrdal Lecture*, Vol. 1, United Nations Publications, 2003.

Oltra, Vanessa et al., "Environmental innovation and industrial dynamics: the contributions of evolutionary economics," *Cahiers du GREThA*, 2008, *28*, 27.

Ottman, Jacqueline and NTC Business Books, "Green marketing: opportunity for innovation," *The Journal of Sustainable Product Design*, 1998, *60.*

Pereira, Ángeles and Xavier Vence, "Key business factors for eco-innovation: an overview of recent firm-level empirical studies," 2012.

Pigou, Arthur Cecil, "The economics of welfare," 1920.

Popp, David, Richard G Newell, and Adam B Jaffe, "Energy, the environment, and technological change," *Handbook of the Economics of Innovation*, 2010, *2*, 873–937.

Porter, Michael, "America\'s green strategy," *Scientific American*, 1991, *264* (4).

Porter, Michael E, "The competitive advantage of nations," 1990.

_ **and Claas Van der Linde**, "Toward a new conception of the environment-competitiveness relationship," *The journal of economic perspectives*, 1995, *9* (4), 97–118.

_ **and Claas van der Linde**, "Green and competitive: ending the stalemate," *Journal of Business Administration and Policy Analysis*, 1999, p. 215.

Pottelsberghe, Bruno Van, Herman Denis, Dominique Guellec et al., "Using patent counts for cross-country comparisons of technology output," Technical Report, ULB–Universite Libre de Bruxelles 2001.

Rave, Tilmann, Frank Goetzke, Mario Larch et al., "The determinants of environmental innovations and patenting: Germany reconsidered," *Ifo Institute for Economic Research: Munich, Germany*, 2011.

Rehfeld, Katharina-Maria, Klaus Rennings, and Andreas Ziegler, "Integrated product policy and environmental product innovations: An empirical analysis," *Ecological Economics*, 2007, *61* (1), 91–100.

Reinhardt, Forest L, "Environmental product differentiation: Implications for corporate strategy," *California management review*, 1998, *40* (4), 43–73.

Rennings, Klaus, "Redefining innovation—eco-innovation research and the contribution from ecological economics," *Ecological economics*, 2000, *32* (2), 319–332.

Requate, Till, "Dynamic incentives by environmental policy instruments—a survey," *Ecological economics*, 2005, *54* (2), 175–195.

_ **and Wolfram Unold**, "Environmental policy incentives to adopt advanced abatement technology:: Will the true ranking please stand up?," *European Economic Review*, 2003, *47* (1), 125–146.

Rodrik, Dani, "Trade and industrial policy reform in developing countries: a review of recent theory and evidence," Technical Report, National Bureau of Economic Research 1993.

Roediger-Schluga, Thomas, *The Porter hypothesis and the economic consequences of environmental regulation*, Edward Elgar Publishing, 2004.

Romer, Paul M, "Increasing returns and long-run growth," *The journal of political economy*, 1986, pp. 1002–1037.

Rubashkina, Yana, Marzio Galeotti, and Elena Verdolini, "Environmental regulation and competitiveness: Empirical evidence on the Porter Hypothesis from European manufacturing sectors," *Energy Policy*, 2015, *83*, 288–300.

Santis, Roberta De, "Impact of environmental regulations on trade in the main EU countries: conflict or synergy?," *The World Economy*, 2012, *35* (7), 799–815.

_ **and Cecilia Jona-Lasinio**, "Environmental Policies, Innovation and Productivity in the EU," *LEQS Paper*, 2015, (100).

Sauvage, Jehan, "The stringency of environmental regulations and trade in environmental goods," 2014.

Schmookler, Jacob, "Economic sources of inventive activity," *The Journal of Economic History*, 1962, *22* (01), 1–20.

_ , *Invention and economic growth* 1966.

Schumpeter, Joseph A, *Capitalism, Socialism, and Democracy. 3d Ed*, New York, Harper [1962], 1950.

Schumpeter, Joseph Alois, *The theory of economic development: An inquiry into profits, capital, credit, interest, and the business cycle*, Vol. 55, Transaction publishers, 1934.

Serres, Alain De, Fabrice Murtin, and Giuseppe Nicoletti, "A framework for assessing green growth policies," 2010.

Sharif, Naubahar, "Emergence and development of the National Innovation Systems concept," *Research policy*, 2006, *35* (5), 745–766.

Solow, Robert M, "A contribution to the theory of economic growth," *The quarterly journal of economics*, 1956, pp. 65–94.

Tobey, James A, "The effects of domestic environmental policies on patterns of world trade: an empirical test," *Kyklos*, 1990, *43* (2), 191–209.

Triguero, Angela, Lourdes Moreno-Mondéjar, and María A Davia, "Drivers of different types of eco-innovation in European SMEs," *Ecological economics*, 2013, *92*, 25–33.

Varsakelis, Nikos C, "Education, political institutions and innovative activity: A cross-country empirical investigation," *Research Policy*, 2006, *35* (7), 1083–1090.

Veugelers, Reinhilde, "Which policy instruments to induce clean innovating?," *Research Policy*, 2012, *41* (10), 1770–1778.

Vries, Frans P De and Cees Withagen, "Innovation and environmental stringency: the case of sulfur dioxide abatement," 2005.

Williamson, David and Gary Lynch-Wood, "Ecological modernisation and the regulation of firms," *Environmental Politics*, 2012, *21* (6), 941–959.

Wooldridge, Jeffrey, *Econometric analysis of cross section and panel data*, Cambridge MA: The MIT Press, 2002.

Xu, Xinpeng and Ligang Song, "Regional cooperation and the environment: Do "dirty" industries migrate?," *Weltwirtschaftliches Archiv*, 2000, *136* (1), 137–157.

Zoboli, Roberto, Valeria Miceli, Susanna Paleari, Massimiliano Mazzanti, Giovanni Marin, Francesco Nicolli, Anna Montini, and Stefan Speck, "Resource-efficient green economy and EU policies," *Resource-efficient green economy and EU policies*, 2014, (2), 1–107.

Zuniga, P, D Guellec, H Dernis, M Khan, T Okazaki, and C Webb, "OECD patent statistics manual," *Francia: OECD Publications*, 2009.