INNOVAR. Revista de Ciencias Administrativas y Sociales
ISSN: 0121-5051
revinnova_bog@unal.edu.co
Universidad Nacional de Colombia
Colombia

Pereira Sánchez, Ángeles; Vence Deza, Xavier
Environmental Policy Instruments and Eco-innovation: An Overview of Recent Studies
INNOVAR. Revista de Ciencias Administrativas y Sociales, vol. 25, núm. 58, octubre-diciembre, 2015, pp. 65-80
Universidad Nacional de Colombia
Bogotá, Colombia

Available in: http://www.redalyc.org/articulo.oa?id=81841166006

- How to cite
- Complete issue
- More information about this article
- Journal's homepage in redalyc.org

Scientific Information System
Network of Scientific Journals from Latin America, the Caribbean, Spain and Portugal
Non-profit academic project, developed under the open access initiative

REVISTA INNOVAR JOURNAL

Environmental Policy Instruments and Eco-innovation: An Overview of Recent Studies[1]

Ángeles Pereira Sánchez
Máster en Desarrollo Económico e Innovación
Universidade de Santiago de Compostela
Galicia, España
ICEDE - Innovación, Cambio Estrutural e Desenvolvemento
Correo electrónico: angeles.pereira@usc.es

Xavier Vence Deza
Catedrático de Economía Aplicada
Universidade de Santiago de Compostela
Galicia, España
ICEDE - Innovación, Cambio Estrutural e Desenvolvemento
Correo electrónico: xavier.vence@usc.es

ABSTRACT: In this paper we conduct a systematic literature review with the aim of understanding the effectiveness of environmental policy instruments, in particular, command and control, market-based instruments and voluntary schemes, in promoting eco-innovation. This study analyzes the information presented in selected papers, mainly from peer-reviewed journals, covering the period 2005-2012. The sample is based on 40 papers traced through a keyword search in Scopus database, representing the main academic journals related to the subject. A few more sources were added after reviewing the list of references from the main papers.

The literature reviewed adopts different approaches and pursues several objectives to understand the relationship between policy instruments and eco-innovation. We find overall evidence that stringency is a key feature of policies for determining the effects of environmental technological change. It is argued that command and control instrument boosts eco-innovation, but continuity in investments depends more on the expected severity of future regulation. Empirical studies confirm that market-based instruments promote more incremental innovation and diffusion of existing technologies than radical innovation. In general, instruments based on economic incentives need to be complemented with stringent controls to be more effective. We conclude that complementarities between measures focused on developers and demanders are necessary in order to foster eco-innovation.

KEYWORDS: Environmental policy, command and control, market-based instruments, voluntary schemes, eco-innovation.

INSTRUMENTOS DE POLÍTICA AMBIENTAL Y ECOINNOVACIÓN: UNA APROXIMACIÓN A ESTUDIOS RECIENTES

RESUMEN: A través de una revisión bibliográfica este trabajo busca analizar la efectividad de los instrumentos de política ambiental, en particular los de mando y control, instrumentos de mercado y planes voluntarios, que promueven la ecoinnovación. Este trabajo analiza la información presentada en 40 artículos de investigación publicados en revistas con procesos de revisión por pares para el periodo 2005-2012, rastreados a través de una búsqueda de palabras clave en la base de datos Scopus, la cual incorpora las principales revistas académicas relacionadas con la disciplina estudiada. Además, se incluyeron algunas fuentes adicionales después de revisar la lista de referencias de los trabajos más destacados.

La literatura revisada adopta diferentes puntos de vista y persigue varios objetivos para comprender la relación entre los instrumentos de política ambiental y la ecoinnovación. En general, encontramos evidencia de que el rigor se establece como elemento clave en las políticas que determinan el cambio tecnológico a nivel ambiental. Entre las conclusiones más se relevantes, se destaca que el instrumento de mando y control impulsa la ecoinnovación, no obstante, es la continuidad en las inversiones lo que más se relaciona con el rigor esperado de las futuras políticas regulatorias. Estudios empíricos confirman que los instrumentos de mercado promueven un mayor incremento en la innovación y la difusión de tecnologías existentes en comparación con los principios de la innovación radical. Por otra parte, se sugiere que los instrumentos basados en incentivos económicos deben ser complementados con rigurosos controles en aras de hacerlos más efectivos. Se concluye además la necesidad de establecer complementariedades entre las medidas enfocadas a los promotores de este tipo de instrumentos y sus solicitantes, con el fin de suscitar procesos de ecoinnovación al interior de las organizaciones.

PALABRAS CLAVE: Política ambiental, mando y control, instrumentos de mercado, esquemas voluntarios, ecoinnovación.

INSTRUMENTOS DE POLÍTICA AMBIENTAL E ECOINOVAÇÃO: UMA APROXIMAÇÃO A ESTUDOS RECENTES

RESUMO: Por meio de uma revisão bibliográfica, este trabalho procura analisar a efetividade dos instrumentos de política ambiental, em particular os de comando e controle, instrumentos de mercado e planos voluntários, que promovem a ecoinovação. Além disso, analisa a informação apresentada em 40 artigos de pesquisa publicados em revistas com processos de revisão por pares no período 2005-2012, selecionados mediante uma busca de palavras-chave na base de dados Scopus, a qual incorpora as principais revistas acadêmicas relacionadas com a disciplina estudada. Ainda, foram incluídas algumas fontes adicionais após revisão da lista de referências dos trabalhos mais destacados.

A literatura revisada adota diferentes pontos de vista e tem vários objetivos para compreender a relação entre os instrumentos de política ambiental e a ecoinovação. Em geral, constatamos que o rigor é estabelecido como elemento-chave nas políticas que determinam a mudança tecnológica no nível ambiental. Entre as conclusões mais relevantes, destaca-se que o instrumento de comando e controle incentiva a ecoinovação; contudo, é a continuidade nos investimentos o que mais se relaciona com o rigor esperado das futuras políticas regulatórias. Estudos empíricos confirmam que os instrumentos de mercado promovem um maior aumento na inovação e na difusão de tecnologias existentes em comparação com os princípios de inovação radical. Por outro lado, sugere-se que os instrumentos baseados em incentivos econômicos devem ser complementados com rigorosos controles a fim de que sejam mais efetivos. Conclui-se que há necessidade de estabelecer complementariedades entre as medidas enfocadas nos promotores desse tipo de instrumentos e seus solicitantes, como o objetivo de suscitar processos de ecoinovação no interior das organizações.

PALAVRAS-CHAVE: Política ambiental, comando e controle, instrumentos de mercado, esquemas voluntários, ecoinovação.

LES INSTRUMENTS DE LA POLITIQUE ENVIRONNEMENTALE ET L'ÉCO-INNOVATION: UN RAPPROCHEMENT À DES ÉTUDES RÉCENTES

RÉSUMÉ : À travers d'un bilan de la littérature, cet article vise à analyser l'efficacité des instruments de la politique environnementale, et plus particulièrement, les instruments de commandement et de contrôle, du marché et des régimes volontaires, qui favorisent l'éco-innovation. Ce document analyse les informations présentées dans quarante articles de recherche publiés dans des revues avec des processus d'évaluation par des pairs pour la période 2005-2012, tracés par une recherche de mots-clé sur la base de données Scopus, qui intègre les principales revues de la discipline liée à l'étude. En plus, certaines sources supplémentaires ont été inclues après avoir examiné la liste de référence des travaux les plus remarquables.

La documentation examinée prend différents points de vue et poursuit divers objectifs pour comprendre la relation entre les instruments de la politique environnementale et l'éco-innovation. Dans l'ensemble, nous avons trouvé des preuves que la rigueur est établie comme un élément clé dans les politiques qui déterminent le changement technologique au niveau environnemental. Parmi les conclusions les plus pertinentes, il faut souligner que l'instrument de commandement et de contrôle favorise l'éco-innovation. Cependant, l'investissement continu est le plus lié à la sévérité attendue des futures politiques réglementaires. Des études empiriques confirment que les instruments de marché favorisent un plus grand accroissement de l'innovation et la diffusion des technologies existantes, par rapport aux principes de l'innovation radicale. Par ailleurs, il est suggéré que les instruments basés sur des primes d'encouragement économique devraient être complétés par des contrôles rigoureux afin de les rendre plus efficaces. On conclut, également, que la complémentarité entre les mesures visant les promoteurs de ces instruments et leurs candidats est une nécessité, afin de générer des processus d'éco-innovation au sein des organisations.

MOTS-CLÉ : Politique environnementale, commandement et contrôle, instruments de marché, régimes volontaires, éco-innovation.

CORRESPONDENCIA: Facultade de Ciencias Económicas e Empresariais, Avenida do Burgo das Nacións s/n, 15782 Santiago de Compostela, España.

CITACIÓN: Pereira Sánchez, Á., & Vence Deza, X. (2015). Environmental Policy Instruments and Eco-innovation: An Overview of Recent Studies. *Innovar, 25*(58), 65-80. doi: 10.15446/innovar.v25n58.52426.

ENLACE DOI: http://dx.doi.org/10.15446/innovar.v25n58.52426.

CLASIFICACIÓN JEL: Q55, Q58, Q52.

RECIBIDO: Marzo 2013, APROBADO: Abril 2014.

Introduction

The role of environmental policy instruments in boosting the development and diffusion of eco-innovations has been studied from different perspectives along recent decades. In this paper, we conduct a systematic literature review with the aim of understanding the effectiveness of different

[1] The authors acknowledge the financial support from the European Regional Development Fund (ERDF) and from Xunta de Galicia (Competitive Reference Group 2008/041 and Project 08SEC008201PR).

types of environmental policy instruments, particularly, command and control, market-based instruments and voluntary schemes.

Eco-innovation can generally be defined as any form of innovation that favorably affects the environment independently of its guiding motivation. There is not only one definition, but there are some characteristics making it different from the conventional innovation term. Firstly, eco-innovation implies a positive effect in relation to the environment in comparison to other alternatives, such as the efficient use of resources, the reduction of pollutant emissions, etc.

In the view of the neoclassic innovation theory it is possible to identify a "*double-externality*" characteristic in eco-innovation (Rennings, 2000), which is related to its social good quality. Innovation processes generally stem in some knowledge spillovers. The appropriability problem implies that different agents can benefit from these spillovers while the company that undertakes the initial effort on research and investment does not receive any reward. That situation, which is a market failure, is due to the relative simplicity to reproduce knowledge in contrast with the obstacles to its creation. Therefore, it can create a disincentive to invest in eco-innovation. In addition, when a company internalizes the environmental damages that it causes, this generates a positive social gain that society does not have to pay for. The company that makes the investment seeking its own profit is not able to take full advantage of the gains created by that investment. That situation can also drive under-investment from the private sector on environmental technologies.

A second feature that derives from the double externality characteristic is the importance of the regulatory framework as a driver for eco-innovation, since it is difficult that the market generates the desirable social level of eco-innovation. This is known as the "*regulatory push/pull effect*" (Rennings, 2000).

In contrast to the neoclassic theory, that considers environmental problems simply as a negative externality derived from production –which must be solved by imposing a cost to the companies, justified in terms of social welfare–, recent views highlight the potentiality of environmental issues as a new way to create competitive advantages (Porter & van der Linde, 1995). They give public policy a new function, with a more dynamic character, thus it can facilitate and promote technological change.

Within the evolutionist approach, innovation systems theory considers environmental problems not as a market failure but rather as an imperfection of the interactions between environmental, social and institutional systems (Rennings, 2000; Foxon & Andersen, 2009). This allows understanding eco-innovation in a broader sense and recognizing it as a way to achieve sustainability goals. From this point of view, public policy has a major role in creating the conditions to favor change and encourage the development and diffusion of eco-innovation by involving all stakeholders.

Environmental innovation has been object of growing attention during the last years. Earlier studies in the field of environmental economics focused on the ability of environmental policy to influence the direction of technological change and on the role of technological policy to supplement the effects of environmental policy; see Popp, Newell and Jaffe (2011), for a recent and comprehensive review about technological change and the environment.

In this paper, we make a review of some recent literature that analyzes the impact of different policy instruments in promoting the development and adoption of eco-innovation, with the aim of enhancing the understanding of this topic and clarifying what type of instrument shows a better performance. In the second section, we explain the research method used to address this question. Next, we synthesize the main types of instruments traditionally used to drive companies' responses to environmental damages. In the central part of the paper, we summarize the main insights from the reviewed studies, trying to confront the advantages and disadvantages of the instruments. We close the paper with some conclusions from this reviewing exercise.

Research Method

The present study develops a systematic literature review, analyzing journal papers for the period 2005-2012. This work focuses on the effectiveness of different policy instruments in promoting eco-innovation. Other sources and papers from previous periods were also taken into consideration in order to establish a background for the role of environmental policy instruments and technological change.

The review was mainly conducted as a structured keyword search in Scopus database, which comprises the main academic journals related to the subject. First, "eco-innovation" and "environmental policy" were used as the main keywords. However, "environmental innovation", "innovation" and "policy instruments", were also combined in consecutive rounds in order to increase the sample. Some other papers were added considering the reference list of the most outstanding works.

The search did not take into account other keywords that could also be representing eco-innovations, such as the three *Rs* in the environment (reducing, reusing, recycling), organic and cleaner production, industrial ecology, etc., since the main objective was to provide an eco-innovation term-specific literature review. We identified that the keywords selected make the sample biased towards European literature, especially German literature.

With an initial sample of 330 papers, we conducted a first reading of abstracts in order to select those that were specifically aimed at testing the effect of environmental policy instruments on eco-innovation. For this review, we adopted a broad definition of eco-innovation, including any type of technology that potentially reduces environmental impacts in relation to alternatives.

After selecting the final sample, made up by 40 papers, we read them and undertook the analysis. The reading process was guided by the following questions:

- What types of policy instruments are being analyzed?
- Does it focus on innovation, adoption or both?
- Does the paper distinguish between different types of eco-innovations (products, processes, etc.) or degrees of novelty (incremental vs radical innovation)?

Accordingly, the main insights are outlined in the central part of this paper.

Environmental Policy and Technological Change

Consideration towards the impact of human activities on the environment is relatively new in economic analysis. It is generally accepted that technological change is necessary to answer the present and future environmental challenges, so in recent years there has been an increasing interest in the study of innovation incentives provided by environmental policy, especially evident in the context of the European Union (Oosterhuis, 2006; CM International, 2007; COWI, 2008, 2009a, 2009b).

Environmental policy is explicitly aimed at dealing with negative externalities originated from economic activities. At the same time, it is usually acknowledged that environmental policy promotes technological change and can also influence its direction (Jaffe, Newell & Stavins, 2003). In that sense, there are two approaches to understand the relation between environmental policy and innovation: the "induced innovation theory" and the "evolutionary theory". The former is based on the idea that R&D constitutes an investment activity guided by profit motivation, therefore, sensitive to changes in relative prizes. Thus, since environmental policy makes environmental inputs implicitly or explicitly more expensive, it works as an incentive to drive R&D (Newell, Jaffe & Stavins, 1998; Goulder & Schneider, 1999; Jaffe *et al*., 2003; Popp *et al*., 2011).

From the evolutionary point of view, R&D activities are guided by rules and routines specific to the company with the logic of satisfying more than optimizing. In that case, the introduction of a boundary through environmental policy is not seen as a cost but as an opportunity to detect new profitable strategies to do things, allowing companies for improving the environment and the economic performance at the same time. This is known as the Porter's *win-win* hypothesis (Jaffe *et al*., 2003). This hypothesis states that properly designed environmental standards can trigger "innovation offsets", which "can not only lower the net cost of meeting environmental regulations, but can even lead to absolute advantages over firms in foreign countries not subject to similar regulations" (Porter & van der Linde, 1995, p. 98).

One of the main interests in environmental economics has been to understand the differential impact of alternative policy instruments on technological change. Over the last 50 years three generations of instruments within environmental policy can be identified (Labandeira Villot & Loureiro García, 2009):

Command and Control

These instruments consist of the establishment of compulsory legal norms for the polluters, and have the purpose of guaranteeing environmental quality levels through the setting of emission limits and the characterization of products and their corresponding pollution levels, as well as production and remediation industrial processes. They usually take the form of bans, limits to the volume of emissions, technical requirements for intermediate and/or final products, specification of the characteristics of technical production processes and decontamination. They also imply a monitoring system to control polluters and economic and/or penal sanctions if not fulfilled.

Economic, Market or Flexible Instruments

These instruments provide flexibility for the polluters by introducing a price for polluting emissions and tend to emulate market's performance. Normally, these are environmental taxes (eco-taxes) or they are based on the creation of a market for tradable emission permits. In this category, financial incentives, such as subsidies, are also included.

Voluntary Agreements

These instruments try to increase flexibility by self-regulation of polluting sectors through a cooperative process. Three variants can be distinguished:

- Public administration establishes a scheme for environmental performance where those agents that comply voluntarily are given technical assistance, public recognition, or a more favorable normative treatment.
- Polluters define themselves the performance scheme without any public intervention.
- The creation and provision of information processes about the environmental damage caused by polluters are established. Normally these processes are driven by the public administration. The schemes work as guides and incentive polluters to modify their performance in order to avoid losing their corporative image and/or customers.

The mechanisms which these instruments work through are coercion, incentives and consent (Chappin, Vermeulen, Meeus & Hekkert, 2009). Using one or several of those instruments, these mechanisms can be directed towards different aims. Although the rationale is mainly related to the compensation of the negative effects that a polluter agent produces –the deterioration of social welfare due to their activity (both currently and in the future)– or to achieve specific environmental objectives (diminishing pollution, ground erosion, deforestation, etc., in accordance with the goal of facing climate change). Other topics, such as reducing environmental policy costs, obtaining some income for the state, a distributive impact, etc., are considered. At the same time, "all of these forms of intervention have the potential for inducing or forcing some amount of technological change, because by their nature they induce or require firms to do things they would not otherwise do" (Jaffe *et al*., 2003, p. 477).

Recent Insights from the Literature

In this section, we present the main insights from the literature review divided into the different types of policy instruments. Each subsection begins with a brief explanation of the theoretical performance of the type of instrument. Then, the results from theoretical and empirical papers are presented.

Command and Control Instruments

Traditionally, environmental policy used to deal with externalities in the environment derived from productive activities through command and control instruments, such as technical norms, emission standards, relative standards or performance standards. The philosophy of this type of instrument is based on the idea that companies must compensate the social damage by assuming the cost of the pollution generated. The existence of asymmetric information (regulators do not know exactly the pollution level generated by each company or sector) makes this standard regulation (the same for every polluter) the easiest option from the point of view of the regulator.

According to Popp *et al*. (2011), typical standards present some disadvantages. From an economic point of view, forcing some firms to adopt very expensive means of controlling pollution may not being cost effective due to differences in costs amongst firms and even in sources of costs within the same firm. At the same time, in particular performance and technology standards could show lack of ambition, or on the contrary being unachievable, generating an economic or political disruption. In relation to technological incentives, Popp *et al*. (2011) notice that technology standards can freeze the development of technologies that might result in greater levels of control. In addition, once the target is achieved there is no financial incentive for firms to continue investing in technological environmental innovations.

On the other hand, the authors still admit an incentive to invest in environmental technologies under a "Best Available Control Technology" standard, by a comparative advantage in relation to the competitors. This type of standards can also benefit those companies that invent and patent better equipment by providing them with a ready market.

From a theoretical point of view, the company that is exposed to an environmental norm has three choices: i) to reduce the level of production and hence the level of pollution (or some other environmental damage), ii) to develop or adopt an innovation which allows reducing its impact in the environment without decreasing the intensity of production, or simply iii) do not comply and pay the fine.

The analysis is usually as follows: each firm faces a series of abatement costs, which stands for the profits that it does not earn because of the internalization of an environmental problem. This situation can be represented with an abatement marginal cost curve that relates decontamination with cost levels. According to a determined emission standard, the firm will invest in new technology by comparing the costs of the conventional technology with the cost of the new technology and the fixed costs. For Requate (2005), who analyses successful adoption of eco-innovation, the cost advantage of the new technology decreases as the standard relaxes. Therefore, there will be a level in the standard that is dependent on fixed costs, and this will define the possibility that all or any of the companies adopt the new technology. "As a consequence, a uniform emission standard does not necessarily have the lowest incentives, in contrast to what has often been claimed in the literature" (Requate, 2005, p. 183).

Vollebergh (2007) finds that incentives are similar when direct regulation and a tax are compared in their effectiveness to promote invention and innovation. Nevertheless, he highlights the fact that companies will only continue investing in R&D and innovation if they expect a stronger stringency of the standard in the future. In relation to this claim, Requate (2005) highlights the importance of the time strategy[2] and the commitment of the regulator when analyzing the incentives for innovation provided by any type of policy instrument.

We can point out as a main advantage of command and control instruments its environmental efficacy, given its compulsory nature. The risk of being sanctioned generally guarantees the achievement of the pursued objective. However, from the economic point of view, the uniform character can imply greater costs than necessary and has little effect in promoting the development and adoption of better and/or new technological solutions, because the incentive disappears once the standard is reached or it does not work when the standard is too soft.

Regarding command and control instruments, one usual affirmation is that they can serve to promote diffusion more than innovation (Mickwitz, Hyvattinen & Kivimaa, 2008). This idea is supported by theoretical models, so these instruments promote the generalized adoption of a known technology (as the standard is usually based on it), or because once a pollution level is reached, there are no more incentives to continue innovating. On the other hand, Vollebergh questions this claim. According to his

[2] In general, Requate (2005) distinguishes between: ex ante regulation, the regulator moves before technological change and is able to make a commitment at this policy level; the myopic regulator does not anticipate a new technology and commitments ex ante at a policy level that is optimal in relation to traditional technology. Ex post regulation: companies move before through the investment in R&D or the adoption of a new technology and the regulator moves after, fitting the level of his policy instrument to the respective product of R&D or the rate of adoption of the new technology. This policy is always consistent in relation to time (the regulator does not have any incentive to change his conduct after the company has moved).

review "standards imposed under CAC (command and control) provide clear signals as to what physical properties of production processes are undesirable, which in turn could be targeted by inventors" (Vollebergh, 2007, p. 28). In the same vein, some authors argue that performance standards offer the right combination between enforcement and flexibility to incentive radical innovation (Kemp, 1997).

After analyzing the effects of different environmental policy instruments in innovation by comparing the results of different theoretical models, econometric studies, surveys and case studies, Kemp and Pontoglio (2011) find evidence, especially in cases studies, that regulation stimulates more radical innovation than market instruments do. Nevertheless, they also point out that the empirical literature also shows that regulations act as a barrier for innovation to increase efficiencies once emissions limits are met.

We sum up below the findings from some recent empirical papers. In relation to the command and control approach, we have to be cautious since many studies, especially those that undertake econometric estimates based on large databases, do not specify the type of instrument they are referring. In this sense, we understand *regulation* as a command and control instrument.

Taylor, Rubin and Hounshell (2005), compare the effectiveness of different policy approaches to induce technological change for the control of SO_2 emissions in power plants in the US. The study confirms that demand-pull, defined as the government's ability to create and destroy niche markets through the details of legislation and regulation, is effective at promoting invention in environmental technology. They also find out that the anticipation of regulation and its stringency are important factors to affect invention. They point out that economic-based instruments (a cap-and-trade mechanism) are less effective at promoting innovation, contrary to what other authors usually hold.

Lanoie, Laurent, Johnstone and Ambec (2007), and Ambec, Cohen, Elgie and Lanoie (2011), analyze the hypothesis defended by Porter and van der Linde (1995), relative to the role of environmental policy in promoting innovation[3]. The authors base their analysis on a survey carried out in 2003 in companies with more than 50 employees in various manufacturing sectors of countries within the OECD (Organization for Economic Co-operation and Development). They estimate three equations: environmental R&D, environmental performance and economic performance. According to these works, the more stringent the environmental regulation is, the greater the impact on the environment. Their results show that performance-based standards considered by the companies to be "moderately important" or "very important" have a positive impact on the probability that a company has a specific budget for environmental R&D. However, they point that technology-based standards do not have an impact, which reinforces the "narrow version" of the Porter Hypothesis.

Other studies try to, at least partially, test the Porter hypothesis. For instance, Johnstone, Haščič, Poirier, Hemar and Michel (2012), confirm the fact that perceived environmental policy stringency positively influences innovation in environmental-related technology. Kneller and Manderson (2012), focus on the relationship between environmental regulation and innovation in the UK manufacturing industry during 2000-2006. They conclude that environmental regulation stimulates environmental R&D and encourages industry to integrate environmental protection into the production process. However, they also find evidence of some kind of crowd-out effect regarding non-environmental innovation.

Kivimaa (2007) uses empirical case studies in the Nordic pulp and paper industry and identifies the simultaneous effect of environmental policy, market and technology factors on innovation. In the case of environmental process innovation, it seems that regulation acts as a main driver, although it is not so clear for product innovation. The author also states that environmental innovations are developed in anticipation of future policy or as the side effects of existing policies. Thus, he highlights the importance of providing clear signals but also sufficient flexibility to explore new technological developments.

Yarime (2008) develops a case study of the *chlor-alkali* industry in Western Europe and Japan to test the effects of environmental regulation on technological change, in particular, distinguishing between end-of-pipe and clean technologies. The EU case shows that when emission standards are not very stringent, companies focus on incremental change through end-of-pipe technologies. This unclear policy also

[3] The authors test the three different versions of the hypothesis theorized by Jaffe and Palmer (Lanoie *et al.*, 2007):

- "Weak" version: it implies that environmental regulation will stimulate certain types of environmental innovation, although there is no guarantee that the direction or the rate of that innovation will be socially profitable.
- "Narrow" version: affirms that flexible environmental policy regimes (taxes on pollution or tradable permits) give companies more incentives to innovate than prescriptive regulation (technology-based standards).
- "Strong" version: it holds that properly designed regulation can induce cost saving innovations and at the same time have a lower cost of fulfilment.

gives incentives to continue using obsolete processes (*i.e.*, it favors technological lock-in). On the contrary, stringent regulation creates a strong and secure demand for clean technologies; however, if the implementation period is not long enough, it takes the risk of leading companies toward the inefficient use of resources, like in the case of Japan. According to the author, this comparative case demonstrates the need to explicitly mandate to phase out the existing pollution-laden technology with a suitable time frame, according to the state of technology development.

Krozer and Nentjes (2008) focus on suppliers and develop a simulation model to examine how environmental policy can encourage innovations in pollution control. Comparing the policy cycle and the innovation cycle, they state that R&D is a response to future, with more stringent emission reduction requirements (*i.e.,* the innovator moves first). Then, the implementation is generally slow under direct regulation, due to the lack of stringency to promote diffusion. Therefore, these authors indicate that strong subsidy must be required in order to offset uncertainty and loss of profitability for innovators.

Belin, Horbach and Oltra (2009), try to establish regional characteristics of eco-innovation by analyzing the *regulatory push/pull* effect. They study, using German data, the influence of regulation activities of public administration on innovation. For French data they focus on the impact of innovation in the fulfilment of norms and regulation by companies. Their analysis shows that the normative role is highly relevant. However, the authors stress the threats of considering eco-innovation as a systematic answer to regulation. "The existence of this *regulatory push/pull* effect should not lead to consider eco-innovations as systematically induced by regulation, and so to under-estimate the role of supply and demand side determinants" (Belin *et al.*, 2009, p. 5). From their point of view, other factors determine the response of a company to new regulation (Table 1).

Focusing exclusively on product eco-innovation, Kammerer (2009) studies the impact of the stringency of environmental regulation and consumer benefit as two of the main factors that can drive environmental innovations in the electrical and electronic appliances sector. His study is based on interviews carried out in 92 firms of this industry in Germany for the period 2004-2006. Of the studied firms, compliance with regulation was very easy or moderately easy by 32%, easy 20% and difficult 14%. In the econometric estimation, regulation shows a high influence on the implementation of product eco-innovation, as well as in its extension to many products. In contrast, the degree of stringency of environmental regulation does not influence the novelty of the innovation, so the application of norms does not work as an incentive in developing innovations for the market.

Kesidou and Demirel (2010) criticize the fact that most studies do not take into account the heterogeneity of firms. Based on the Government Survey of Environmental Protection Expenditure by Industry of the United Kingdom for the year 2006, they consider the hypothesis that the stringency of environmental regulation (approached as the company's operating and capital costs) affects companies in different ways according to their innovative character. More precisely, they state that less innovative firms respond to changes in environmental regulation with the objective of decreasing their operating costs. In turn, companies that are more innovative tend to have a more active profile, and invest in environmental innovation for the strategic reason of gaining an advantage in relation to their competitors. "Consequently, stricter regulations may not be the main driver of eco-innovation for highly innovative firms that are already involved in environmental R&D" (Kesidou & Demirel, 2010, p. 8). Focusing exclusively on companies in their sample that invest in environmental R&D, they show that "environmental regulation plays an important role in stimulating environmental research and development in firms that are not at the technological frontier with respect to eco-innovation, while it exerts no impact upon highly innovative firms that are ahead of their peers in eco-innovation" (Kesidou & Demirel, 2010, p. 16).

TABLE 1. Determinants of Environmental Innovation

Regulation and policy determinants	• Implementation of environmental policy instruments: economic and regulatory instruments • Existence and anticipation of environmental regulations • Regulatory design: stringency, flexibility, time frame
Supply side determinants	• Cost savings, productivity improvements • Organizational innovations: environmental management systems, extended producer responsibility • R&D activities • Industrial relationships, supply chain pressure, networking activities
Demand side determinants	• Environmental consciousness and consumers' preferences for environmentally friendly products • Expected increase in market share or penetration of new market segments

Source: Belin *et al.* (2009, p. 4).

In a later study, Demirel and Kesidou (2011) exploit the same source of statistical data to investigate the extent to which different types of eco-innovation —such as end of pipeline technologies (EOP), integrated technologies or environmental R&D— are driven by different factors. By analyzing the introduction of eco-innovations in terms of environmental regulation, they find a U-shaped relationship: regulation affects investments in EOP technologies and in environmental R&D. However, the impact is very limited when it comes to increasing the levels of these investments. "This suggests that regulations are being effective in converting firms to eco-innovators either at the lower or the higher end of the eco-innovation spectrum" (Demirel & Kesidou, 2011, p. 1552).

Based on data from the German Community Innovation Survey 2009, Horbach, Rammer and Rennings (2012), examine how different factors (present and future regulation, subsidies, self-commitment, cost savings and customer requirements) affect different types of process and product eco-innovation. In the case of process innovation, the authors find that regulation is an important driver for all environmental impact areas, except for the field "reduced material and energy use" that seems to be more influenced by cost savings. In addition, the marginal effects of present and future regulation are higher for end-of-pipe oriented areas. Regarding product eco-innovation, future regulation is essential for all areas (energy consumption, emission reductions and recycling) but present regulation is only significant for energy consumption and recycling.

Noailly (2012) carries out an empirical analysis of three types of policy instruments (regulatory energy standards, energy taxes and governmental energy R&D) in the specific case of the building sector. Using patent counts for specific technologies related to energy efficiency in buildings in seven European countries during the period 1989-2004, the author estimates that a strengthening of 10% on the minimum insulation standards for walls would increase the likelihood to file additional patents by about 3%. On the other hand, energy prices show no significant effect and governmental energy R&D supports very small impact on patenting activities.

Based on the case of the Swedish regulatory approach during the period 1970-1990 to lower emissions in the metal smelter and pulp and paper industry, Bergquist, Söderholm, Kinneryd, Lindmark and Söderholm (2013), conclude that performance standards granted flexibility to firms in order to select the appropriate compliance measures. In addition, the extended compliance periods and the R&D projects enabled by the collaboration between focal companies, authorities and research institutes were the key to succeed.

Market-based Instruments

Following Vollebergh (2007), economists generally prefer market-based instruments because of their economic efficiency, since they allow minimizing the costs of environmental policy (static efficiency) and also encourage technological progress to fight against the deterioration of the environment (dynamic efficiency). Popp *et al*. (2011), note that market-based instruments provide powerful incentives to adopt new environmental technologies to the extent that it is worth to invest in new equipment if its cost is sufficiently low; and that is specially true for flexible policies that allow the company to choose the best way to achieve the political goal.

The theoretical analysis starts with the abatement marginal cost curves. According to Labandeira and Loureiro (2009), the establishment of a price-through an environmental tax or by creating a market for tradable permits, allows all polluters to equal their marginal abatement cost at the price p, since it is better to avoid polluting than to pay when the costs of polluting are under this price. Thus, abatement cost curves are implicitly revealed and the problem of asymmetric information between the regulator and the regulated agents can be solved. It is possible to achieve the same result at a lower cost, that is to say, minimizing environmental policy costs. Moreover, the incentive to continue reducing the level of pollution remains: companies have to pay for the residual pollution, so it might be interesting for them to continue investing in environmental R&D and innovation with the aim of improving the efficiency of their processes and pay less in the future.

The difference between a tradable permits scheme and an eco-tax is that, generally, tax remains at its initial level. On the contrary, as technology spreads, causing a shift of the abatement cost curve, the permit price falls (except if the number of permits was limited). This means that now polluting is less costly. Therefore, the level of pollution in equilibrium will be higher. Vollebergh (2007) notes that this can be seen as the rebound effect of the invention, which depends largely on the commitment and the time horizon of the policy.

Requate (2005) mentions that emission taxes provide a stronger incentive for R&D and investment in new technology, in relation to permits if there are myopic environmental policies or long-term commitments. As this author states, "The reason is that the permit price falls if new technology diffuses, providing a lower incentive for firms with old technology to invest in pollution reducing technology" (Requate, 2005, p. 193). Opposed to this view, Krugman (2010) defends the ability of the tradable permits scheme as it provides a "selfish motive" to generate fewer emissions. Nevertheless, Krugman (2010) does not assess the potential of these instruments for eco-innovation. For the author, the tradable permits scheme presents some advantages:

- There is a limited number of permits allowed to emit a specific pollutant.
- It gives everyone an incentive to reduce pollution. Buyers do not have to get as many permits if they are able to reduce their emissions and sellers can get rid of more permits if they manage to reduce their own emissions.
- The Government knows the amount of pollution that exists, but polluters do not know the emissions price.
- If the Government only issues the permits and collects the revenue, this scheme works like a tax. On the other hand, if trade is allowed, the potential revenue will revert in the industry. Moreover, from the political point of view, it may make it easier to adopt a tough policy against climate change.

Instead, with a tax on pollution:

- Polluters know what price must pay, but the Government does not know how much pollution is generated.
- It involves a cost to the private sector, generating an income for the Government.

In general, market-based instruments have a number of advantages. According to Vollebergh (2007), public authorities need much less technical information to design a tax than a technological standard; this reduces the possibility of rent-seeking and the potential to shape innovation in an erroneous way. In addition, taxes allow more flexibility for the regulated agents than standards, as they can choose the best choice to address the environmental problem according to their possibilities.

Requate (2005) reviews partial equilibrium microeconomic models and carries out an analysis of the abatement marginal cost function faced by a company, and contrasts the incentives that different environmental policy instruments represent for the adoption and development of advanced abatement technologies. The results vary depending on the adoption or innovation model, according to the strategic planning and commitment of the regulator, or depending on the extent of competitive market conditions. The main conclusion is that "instruments which provide incentives through price mechanism, by and large, perform better than command and control policies" (Requate, 2005, p. 193). However, the author emphasizes that it is important that the regulator anticipates new technologies or responds optimally to the invention and adoption of new technology.

Requate (2005) also highlights that under competitive market conditions various studies suggest similar results whether there is ex ante commitment or ex post optimal policies. On the contrary, when studies analyze imperfect conditions scenarios, the outcomes can be very different. The timing strategy of the regulator, that is to say, the moment or stage in which the instrument is applied, is crucial to determine what type of instrument can be more effective.

On the other hand, there are some claims about the limited ability of economic instruments to promote radical changes. As stated by Vollebergh, "The greater flexibility provided by TDP (tradable permits) systems seems to direct both R&D and innovation efforts away from fundamental research on entirely new opportunities, and towards using the flexibility opportunities provided by this type of regulation of existing technology" (Vollebergh, 2007, p. 28). Kemp and Pontoglio (2011) arrive to a similar conclusion; they believe that market-based instruments are good to stimulate incremental change and diffusion of technology, but not to promote future innovations.

Despite the referred neoclassical preference for market-based instruments, Rennings (1998, pp. 7-8) states that:

- The dynamic efficiency of standards can be improved substantially by "technology forcing" in command and control regime (rules of permanent reductions or long-term standards going beyond existing technologies) and by repeated negotiations in a voluntary agreements regime (continued process of negotiations after each monitoring phase).
- The dynamic efficiency of taxes can be mitigated in the political process. Total environmental costs for industry are generally higher under a tax regime than under alternative regimes of command and control or negotiated agreements (firms have to pay for residual emissions and pollution). This can lead to a tendency to impose relatively low taxes with little impact on innovation. It is important to realize that it is precisely the innovation-friendly attribute of taxes (charging firms for residual emissions) what can lead to this counter-effect (low taxes with low impacts).
- A regime of free tradable emission permits is preferable according to the criteria of dynamic efficiency, since it combines the advantage of a tax system with a direct control regime: environmental improvements are achieved at the lowest costs and there is no uncertainty about the total level of emissions reduction. However, relevant issues to innovation must be considered, such as the behavior of interest

groups in the political process, transaction costs or distributive consequences.

- The superiority of market-based instruments has been validated for situations with perfect competition and full information, but the situation may change under imperfect competition conditions. When companies get a "strategic advantage" of innovation, standards may be more appropriate to stimulate innovation.

The main results of empirical studies on the impact of market-based instruments in the development and adoption of eco-innovations are presented below.

Mazzanti and Zoboli (2006a) consider specifically the EU policy of End-of-Life Vehicles as a representative case study of a multiple industry-producer responsibility instrument. In particular, they explore the effectiveness of a free take-back instrument to influence industrial actors and to contribute to a sustainable innovation path. Their analysis leads them to conclude that the dynamic efficiency of this type of instruments depends on where, along the value chain and how, in terms of net cost allocation, the specific incentive is introduced.

The already cited studies by Lanoie *et al*. (2007) and Ambec *et al*. (2011), reveal that flexible instruments, such as taxes on pollution, are not very important for eco-innovation as compared to command and control instruments. Therefore, the authors stand that the narrow version of the Porter hypothesis according to which flexible environmental policy is more effective in promoting this kind of innovation is not observed[4].

Fischer and Newell (2008) assess how different policies for reducing CO_2 and promoting innovation and diffusion of renewable energy perform in relation to emissions reduction, efficiency, renewable energy production and R&D. Although they conclude that the optimal policy is a combination of emission price and subsidies, the analysis of single instruments allows them to establish the following ranking: i) emissions price; ii) emissions performance standard; iii) fossil power tax; iv) renewable share requirement; v) renewable subsidy; and vi) R&D subsidies. Emissions price receives the first position since it addresses effectively all the objectives: it gives incentives for fossil energy producers to reduce emissions intensity, for consumers to conserve, and for renewable energy producers to expand production and to invest in R&D to reduce their costs.

Greaker and Pade (2009) focus on how the existence of an upstream abatement technology sector affects optimal environmental policy. Results show that setting emission reduction targets over marginal environmental costs will lead to more domestic environmental R&D, since it stimulates competition between abatement equipment suppliers. Taking the case of the EU Emissions Trade System (ETS) and provided that governments are responsible for trading international quotas and allocating allowances, the authors foresee that it will act as an incentive to research and deployment of new abatement technologies only if it is sufficiently strict. However, it gives power plants very few incentives to invest in carbon capture and storage equipment because it does not affect the number of allowances required.

The previously cited work by Krozer and Nentjes (2008) concludes that economic instruments are partly better than standards for suppliers, since they limit uncertainty, provide a group of willing buyers (who want to reduce their residual cost of marginal emission) and, from the policy cycle perspective, they are faster to prepare.

Demirel and Kesidou (2011) examine the extent to which firms invest in environmental protection because of environmental taxes. Their results are not significant for any of the three types of eco-innovation analyzed (EOP, process integrated, environmental R&D) but they relate this finding to the scarce use and stringency of this kind of instrument. As indicated by these authors, "In the case of UK environmental taxes have not been frequently used as a means of regulating levels of pollution as environmental laws historically have been the preferred policy instrument in this field. In addition, environmental taxes are often set at a low level and the effects are therefore low or insignificant" (Demirel & Kesidou, 2011, p. 1553).

Johnstone, Haščič and Popp (2009), use patents as an indicator of technological innovation in the sector of renewable energies and confirm that the effect of specific policies varies according to technology. In their panel study over 25 countries in the course of 26 years, they assert that economic instruments that are not aimed at a specific technology, as the renewable energy certificates, do not promote technologies that are far from the market, as solar energy. On the other hand, the feed-in tariffs scheme guarantees a specific price according to technology, so this mechanism creates a market for more costly technologies, for instance solar energy. The authors also observe that when policies oblige companies to use additional renewable energies but allow them freedom of means, companies normally choose less costly technologies.

[4] It is partially supported when comparing performance-based and technological-based standards. See comment on previous sub-section.

Sterner and Turnheim (2009), by adopting a hybrid (economic and engineering) approach, analyze a case to identify the effect of Refunded Emission Payments (REP) both on innovation and on the adoption and diffusion of technologies to reduce industrial emissions of nitrogen oxides (NOx) in Sweden. After a series of specific policy initiatives in 1992, the Swedish Parliament launched the REP to achieve a faster reduction of nitrogen oxides and to provide incentives for a cost-effective reduction from the large combustion plants for energy production. It performed a sequential inclusion of participants (seven sectors: heat and energy, pulp and paper, metal, waste, food, wood and chemical), justified according to the decrease in control equipment costs. In the absence of control equipment, emissions were calculated upon emission levels *per* output, which were very high with the purpose of encouraging operators to undertake real measures. The REP mechanism rewarded combustion units that reduced their emission intensities to levels that were lower than the average. The units with lower emission levels were clear beneficiaries, whilst those who were above the average had to make a net payment. According to the authors, this instrument had a number of advantages over the others: it produced less aversion by pollutant companies, it was easy to implement and it had no effect on the price of the product.

However, Sterner and Turnheim (2009) acknowledge that REP did not act alone, but other factors contributed to the process of emission reductions and technological change. According to their analysis, the determinants commonly identified by power plants operators and suppliers in order to make investments in control technology, were the maximum allowed emission levels (therefore a CAC approach), the REP scheme and its economic incentive, and the application of environmental strategy and management.

Kumar and Managi (2010) develop a case study to understand the induced innovation effect of an Emissions Trade System to regulate SO_2 emission within the frame of the US Clean Air Act Amendments. Applying this study to data from electricity-generating plants, their estimate shows a small induced effect of 1-2% in comparison to the overall technological progress (7-8%) during the period 1995-2007.

Adopting the perspective of sectoral innovation systems, Rogge and Hoffmann (2010) analyze the impact of the European Union Emissions Trade System (EU ETS) as a flexible instrument of climate policy. Its recent application (since 2005) leads the authors to perform a case study based on 42 interviews with key actors in the sectoral innovation system within the German energy sector. They study the perceived impacts according to four parts of the sectoral system: knowledge and technologies, actors and networks, institutions and, finally, demand. The results show that the main impacts of this scheme occur in coal burning plants with regard to the corporate culture of companies.

In relation to knowledge and technology, the authors find that the European emissions trading scheme accelerates the innovation process in general (both the diffusion of existing technologies and R&D in new technologies), and especially, in power plants from coal. Additionally, it promotes research, development and demonstration projects related to CO_2 capture and storage, which is also favored by the market potential due to expectations on the global extent of stringent climate policies; it strengths R&D for efficiency in fossil-fuel power plants; but it only indirectly benefits R&D in renewable energy technologies. According to the authors, this latter observation is due to the existence of other instruments in Germany that had already created favorable conditions for the development of renewable power such as the feed-in tariffs scheme and the consequent pull market.

Regarding actors and networks, the impact of the EU ETS is significant for coal-fired power plants. This instrument leads to a significant increase in spending on R&D, especially for corporate actors (power generating plants and technology providers, the latter also driven by carbon reduction policies in other countries) affiliated to the technological regime of coal. There is not a significant impact on innovation networks in general but there is it in R&D carbon capture and storage committed actors. Rogge and Hoffmann (2010) also identify changes in attitudes amongst corporate institutions for climate change. They focus on the integration of this scheme as a standard in business structures and procedures, and they especially emphasize the incorporation of the criterion of CO_2 price to take decisions in the innovation process. For the authors these changes are really important. "We argue that these corporate institutional changes in firms' CO_2 culture should not be overlooked, as they may be the key to understanding the innovation impact of the EU ETS. They may also prepare the ground for the transition to a low-carbon sectoral innovation system for power generation technologies" (Rogge & Hoffmann, 2010, p. 7648).

Finally, the impact of the EU ETS on demand seems to be quite limited, due to the lack of stringency and predictability of the new instrument, as well as to the relevance of other factors, such as fuel prices, supply security concerns, and public support measures for renewables. In fact, the authors confirm the remaining interest in building new coal plants, and the additional incentive for the modernization of existent plants based on fossil fuels.

Daugbjerg and Svendsen (2011) examine the differential impact of supply and demand side economic instruments in the development of two successful eco-industries in Denmark, the wind energy industry and farming. The key instrument of the Danish government policy to promote wind energy is based on direct demand side instruments. Although firstly, there is a CAC instrument –power plants are obliged to buy wind power–, this is supported by an economic instrument: all consumers pay a special rate called PSO (Public Service Obligations) in the electricity bill, which responds to a "Feed in tariff" scheme. The success of this industry (around 20% of the electricity in Denmark comes from wind turbines) is attributed to the severity of this tax scheme.

Since the 70's, the Danish Government also promoted organic farming with direct subsidies to farmers as the main instrument to facilitate the conversion from conventional to ecological agriculture. In recent years this was accompanied by other indirect instruments such as subsidies for extension services and, more importantly, significant funds for research in organic agriculture. Despite being an internationally strong industry, domestically, the results are less striking. "Our findings indicate that the reliance on demand-side measures in the wind energy sector has been more effective than the extensive and predominant use of supply-side instruments in the organic food sector though some demand-side instruments have been applied too. However, taxation on power generated by fossil fuels seems to have had a more profound impact on the growth in wind energy than the pesticide tax on the growth of the organic food sector" (Daugbjerg & Svendsen, 2011, p. 304).

The differences between the development of the Danish wind energy industry and organic farming might be related to the different performance of instruments based on incentives. In this sense, although Jaffe *et al*. (2003) review empirical studies in which positive economic incentives (such as subsidies) appear to be more effective than "equivalent" taxes in encouraging technology diffusion. They suggest that these instruments present some disadvantages, "First, [...] adoption subsidies do not provide incentives to reduce utilization. Second, technology subsidies and tax credits can require large public expenditures per unit of effect, since consumers who would have purchased the product even in the absence of the subsidy still receive it" (Jaffe *et al*., 2003, p. 503).

Voluntary Approaches

In the latest years of the twentieth century, the belief that companies needed flexibility to meet their environmental goals led to the extension of voluntary instruments. They represent a commitment of companies "to improve their environmental performance beyond what the law demands" (OECD, 2000). One of the most typical examples of this approach are the environmental management and audit programs according to an international standard like the ISO 14001 or the European scheme EMAS. We can also include in this category those called information and communication measures. In this sense, we refer for instance to the life cycle assessment activities of products, waste disposal and take-back systems, eco-labelling, provision of information, benchmarking, and so on. It should be noted that some of these initiatives may also be compulsory by legal requirements.

Environmental management and audit programs involve a variety of practices regarding the integration of environmental considerations into production decisions, the adoption of practices and improvement methods that involve some self-regulation by the concerned company. Moreover, these schemes imply the realization of environmental controls, as well as the evaluation and reporting of compliance with the certificated program. According to Frondel, Horbach and Rennings (2008) environmental management systems (EMS) "have become a vital supplement to mandatory environmental policies based on regulation and legislation" (Frondel *et al*., 2008, p. 154).

The main advantage of this type of scheme is that the company itself is interested and committed to carrying out environmental measures, so that there is no political cost. However, the lack of sanctions for non-compliance also means that the effect can be virtually zero for both the environment and technological change and become like a simple label that improves the image of the company adopting it.

In several studies, the relationship between the implementation of an EMS and the development and adoption of eco-innovations is associated with the generation of information that allows firms to initiate environmental R&D and learning processes about the possibilities of improving processes and products. In turn, this is determined by a firm's environmental commitment (Horbach, 2008; Wagner, 2008) or its strength in environmental issues (Kesidou & Demirel, 2010). According to Horbach (2008) "an environmentally oriented research policy not only has to regard traditional instruments like the improvement of the technological capabilities of a firm, but also, the coordination with soft environmental policy instruments like the introduction of environmental management systems" (Horbach, 2008, p. 172).

According to Rave, Goetzke and Larch (2011), the EMS is positively related to eco-innovation when compared to conventional innovation; it leads to more continuous eco-innovation activities and acts as a relatively important determinant of eco-innovations only new to the firm. With regard to types of innovation, they find a positive association with process eco-innovations and a negative association with product eco-innovation. Most of the studies find a positive relationship between EMS and process innovation but no effect on product innovation (Rennings, Ziegler, Ankele & Hoffmann, 2006; Wagner, 2007; Horbach, 2008).

Sometimes, the relationship between EMS and innovation depends on how the implementation of EMS is measured. For instance, Wagner (2007) builds an index to control the level of implementation of EMS in opposition to certification because of the opportunistic behavior and institutional problems that it can generate. We can also highlight the study by Rennings *et al*. (2006), which focuses on the influence of the different characteristics of EMAS, such as the maturity of the scheme, its organizational scope –strong participation of general management, distribution and R&D department in further development of EMAS– and its strategic importance. All these characteristics are found to be important determinants of environmental process innovations and not related to product eco-innovations. Nevertheless, according to their estimation, learning processes triggered by EMS have a positive influence on environmental product innovations.

Frondel *et al*. (2007) and Demirel and Kesidou (2011), distinguish the influence of the EMS depending on the type of process eco-innovation. While the former acknowledges the positive influence of general management systems and that specific environmental management tools tend to favor clean production, Demirel and Kesidou consider it is an important driver for investment in environmental R&D and end of pipe technologies, whereas it has no effect in integrated technologies. "A plausible explanation of this finding is related to the innovative heterogeneity of firms, where the least innovative firms benefit from having an organizational environmental structure to support them with the minimum compliance requirements through end of pipeline, while the most innovative firms use EMS as an innovation platform to build upon for environmental R&D" (Demirel & Kesidou, 2011, p. 1554).

The already cited study by Horbach *et al*. (2012) reveals that in the case of Germany self-regulation is especially relevant for the area of recycling, where there is a long tradition and commitment from industry.

Other studies give these voluntary schemes relative importance in the promotion of eco-innovation (or minor importance, as Rehfeld, Rennings & Ziegler, 2007). Although Mazzanti and Zoboli (2006b) found a positive relationship between innovation outputs and voluntary audit schemes, they still conclude that the innovative content of these programs is related to the fact that only a limited number of innovative companies really exploit them. According to the study by Frondel *et al*. (2008), the most important reasons to introduce an audit program are the desire to improve corporate image, to save in the management of waste and the use of resources as well as to increase the efforts in complying with norms. The study does not find association between abatement activities and the adoption of EMS. Therefore, they conclude that the adoption of EMS does not seem to stimulate innovation and abatement measures. "(...) [it] appears to be particularly plausible in the absence of sanctions on lack of improvement" (Frondel *et al*., 2008, p. 158).

Regarding voluntary information and communication initiatives, most of studies associate these measures with product eco-innovation. Kammerer (2009), who identifies these activities as companies' green capabilities, proves that, as a whole, these skills positively influence the accomplishment of eco-innovations, extension of eco-innovation to a wide range of products as well as the possibility to offer a greater degree of novelty. Rehfeld *et al*. (2007) also recognize the importance of measures related to waste disposal or take-back systems. "Thus, if a manufacturer has a continued interest in his product, even after its useful phase, environmentally friendly product innovations such as recycling are far more probable" (Rehfeld *et al*., 2007, p. 98). Wagner (2008) argues that these measures provide an additional positive effect in a company's propensity to develop an eco-innovation. He holds that the experience with eco-labelling can result in better knowledge about the product benefits, acting as an incentive for the company to develop new eco-products as well as favoring internal training. Furthermore, providing information to consumers can induce additional demand if there is an environmentally orientated segment of consumers, acting also as an incentive so that a company carries out a product eco-innovation. Rennings *et al*. (2006) also find that the explicit consideration of environmental aspects in product development has a positive influence on environmental process innovations.

Conclusions

The concept of eco-innovation allows setting together the goals of improving the environment and the competitiveness of companies and countries. In recent years, there has been a growing interest amongst researchers in the role of public policy to drive environmental technological change. Based on a systematic literature review of papers and other documents published during the period 2005-2012 about this topic, we have studied the impact of different types of instruments on eco-innovation.

It is a difficult task to determine which type of instrument works best regarding eco-innovation, for several reasons. First, different questions are driven in each study so we can pay attention to process or product eco-innovation, innovation or adoption and diffusion processes, incremental or radical eco-innovation, type of eco-innovation (end of pipeline technologies, process-integrated technologies or environmental R&D), type of company and sector being affected, etc. It has been suggested by several authors that combining different policy instruments and other factors for a more cost-effective promotion of eco-innovation is necessary; on this regard, Del Río, Carrillo-Hermosilla and Könnölä (2010), suggest a framework considering the different barriers and types of eco-innovation (process-product, mature-immature, radical-incremental).

Secondly, the findings are sometimes limited and weak because the lack of specific statistical data and eco-innovation indicators obliges to work with proxies and, hence, be more based on the perceptions of interviewed agents. Thirdly, due to all the variety of research focus in the literature reviewed, a comparison would not be very accurate.

Following the neoclassical approach, public policy is necessary to address the double-externality problem that characterizes eco-innovation. Therefore, policy instruments are aimed at correcting a market failure that occurs at the development stage –lack of incentives to invest in R&D by private companies due to the lack of property rights regarding knowledge– and/or at the diffusion stage –under-investment due to the difficulty of companies to appropriate all the benefits provided by environmental innovation–. Most of the papers reviewed follow a neoclassical approach, therefore, the effectiveness of a single policy instrument or type of instrument is analyzed.

Command and control instruments are usually defended because of their environmental efficacy, as they are based on the coercion mechanism. In relation to technological change, it is argued that they impulse first eco-innovation, but continuity in investments is related to the expected severity of future regulation. In this sense, anticipation and stringency in establishing a clear signal seem to be important factors influencing the efficiency of regulation in promoting R&D. In order to promote diffusion, a suitable time frame and a certain degree of flexibility appear as relevant factors as well.

Market based instruments are preferred by economists because of its static and dynamic efficiency. In our review, there is evidence on how they promote more incremental innovation and diffusion of existing technologies than new paths of technological development. This fact is attributed in some cases to the lack of tradition in the use of these instruments or to its weak stringency. In general, instruments based on incentives need to be complemented with strict controls to be more effective. Finally, voluntary instruments, as those related to environmental management systems or information and communication measures, present the advantage of not having political cost. A positive finding of this review is that they can drive learning processes within companies, which are important to drive more process and product eco-innovations. Nevertheless, their influence is relative because of the lack of penalty for non-fulfilment.

The neoclassical approach is limited when also social and institutional change is relevant for eco-innovation. When eco-innovation requires not just a technological change but also changing patterns of production and consumption, which usually implies a more radical change, the evolutionist approach is considered more useful. The paper by Rogge and Hoffman (2010) included in our review, studies the potential of the EU ETS to promote a radical change regarding climate change. Although the authors conclude that this flexible instrument is affecting the direction of technological change in the power generation sector, it is worth mentioning that the insights from the examination of different parts of the sectoral innovation system support their claim for a coordinated policy mix targeting the decarbonization of the sector. Other studies also confirm the necessity of complementarities between measures affecting suppliers and demanders, in order to allow the development and diffusion of radical new technologies.

An interesting area for further research is that concerning the economic and environmental effects of applying different instruments, possibly with a sectoral focus more than a micro approach, and not merely focused on quantitative but qualitative changes. In that sense, as we understand eco-innovation as a way to achieve sustainability goals, we would like to note that there is a need for designing instruments and policies that go beyond the scope of compensating in return for environmental damages. Policy-makers should advance in alter the game rules to favor eco-innovation as a strategy for sustainability. In this sense, more research adopting an evolutionist approach is required.

References

Ambec, S., Cohen, M. A., Elgie, S., & Lanoie, P. (2011). *The Porter Hypothesis at 20: Can Environmental Regulation Enhance Innovation and Competitiveness?* Retrieved from http://ssrn.com/abstract=1754674.

Belin, J., Horbach, J., & Oltra, V. (2009). Determinants and specificities of eco-innovations – An econometric analisys for France and Germany based on the Community Innovation Survey. Utrecht.

Bergquist, A. K., Söderholm, K., Kinneryd, H., Lindmark, M., & Söderholm, P. (2013). Command-and-control revisited: environmental compliance and technological change in Swedish industry 1970-1990. *Ecological Economics*, *85*, 6-19. doi:10.1016/j.ecolecon.2012.10.007.

Chappin, M. M. H., Vermeulen, W. J. V., Meeus, M. T. H., & Hekkert, M. P. (2009). Enhancing our understanding of the role of environmental policy in environmental innovation: adoption explained by the accumulation of policy instruments and agent-based factors. *Environmental Science & Policy*, *12*(7), 934-947. doi:10.1016/j.envsci.2009.06.001.

CM International (2007). *Designing environmental policy to be innovation friendly. Final Report*. Boulogne- Billancourt: CM International.

COWI (2008). *Promoting Innovative Business Models with Environmental Benefits. Final Report*. EU Commission - DG Environment.

COWI (2009a). *Bridging the Valley of Death: public support for commercialisation of eco-innovation*. Final Report, (May). EU Commission - DG Environment.

COWI (2009b). *The Potential of Market Pull Instruments for Promoting Innovation in Environmental Characteristics. Final Report. Synthesis*. EU Commission - DG Environment.

Daugbjerg, C., & Svendsen, G. T. (2011). Government intervention in green industries: lessons from the wind turbine and the organic food industries in Denmark. *Environment, Development and Sustainability*, *13*, 293-307. doi:10.1007/s10668-010-9262-8.

Del Río, P., Carrillo-Hermosilla, J., & Könnölä, T. (2010). Policy strategies to promote eco-innovation. *Journal of Industrial Ecology*, *14*(4), 541-557. doi:10.1111/j.1530-9290.2010.00259.x.

Demirel, P., & Kesidou, E. (2011). Stimulating different types of eco-innovation in the UK: Government policies and firm motivations. *Ecological Economics*, *70*(8), 1546-1557. doi:10.1016/j.ecolecon.2011.03.019.

Fischer, C., & Newell, R. G. (2008). Environmental and technology policies for climate mitigation. *Journal of Environmental Economics and Management*, *55*(2), 142-162. doi:10.1016/j.jeem.2007.11.001.

Foxon, T., & Andersen, M. M. (2009). The greening of innovation systems for eco-innovation - Towards an evolutionary climate mitigation policy. *Proceedings of the DRUID Summer Conference 2009 on 'Innovation, Strategy and Knowledge'*. Copenhagen Business School, Denmark, 18-20 June 2009.

Frondel, M., Horbach, J., & Rennings, K. (2008). What triggers environmental management and innovation? Empirical evidence for Germany. *Ecological Economics*, *66*(1), 153-160. doi:10.1016/j.ecolecon.2007.08.016.

Goulder, L. H., & Schneider, S. H. (1999). Induced technological change and the attractiveness of CO_2 abatement policies. *Resource and Energy Economics*, *21*, 211-253.

Greaker, M., & Pade, L. L. (2008). *Optimal CO_2 abatement and technological change. Should emission taxes start high in order to spur R&D?* (No. 548). *Statistics*.

Horbach, J. (2008). Determinants of environmental innovation—New evidence from German panel data sources. *Research Policy*, *37*(1), 163-173. doi:10.1016/j.respol.2007.08.006.

Horbach, J., Rammer, C., & Rennings, K. (2012). Determinants of eco-innovations by type of environmental impact — The role of regulatory push/pull, technology push and market pull. *Ecological Economics*, *78*, 112-122. doi:10.1016/j.ecolecon.2012.04.005.

Jaffe, A. B., Newell, R. G., & Stavins, R. N. (2003). Technological change and the environment. In: K. G. Maler & J. Vincent (Eds.). *Handbook of Environmental Economics (vol. I)*. The Netherlands: North-Holland.

Johnstone, N., Haščič, I., Poirier, J., Hemar, M., & Michel, C. (2012). Environmental policy stringency and technological innovation: evidence from survey data and patent counts. *Applied Economics*, *44*(17), 2157-2170. doi:10.1080/00036846.2011.560110.

Johnstone, N., Haščič, I., & Popp, D. (2009). Renewable energy policies and technological innovation: Evidence based on patent counts. *Environmental and Resource Economics*, *45*(1), 133-155. doi:10.1007/s10640-009-9309-1.

Kammerer, D. (2009). The effects of customer benefit and regulation on environmental product innovation. Empirical evidence from appliance manufacturers in Germany. *Ecological Economics*, *68*(8-9), 2285-2295. doi:10.1016/j.ecolecon.2009.02.016.

Kemp, R. (1997). *Environmental policy and technical change. A comparison of technological impact of policy instruments*. Cheltemham: Edward Elgar.

Kemp, R., & Pontoglio, S. (2011). The innovation effects of environmental policy instruments — A typical case of the blind men and the elephant? *Ecological Economics*, *72*, 28-36. doi:10.1016/j.ecolecon.2011.09.014.

Kesidou, E., & Demirel, P. (2010). On the drivers of eco-innovation: empirical evidence from the UK. Nottingham University Business School Research Paper No. 2010-03.

Kivimaa, P. (2007). The determinants of environmental innovation: the impacts of environmental policies on the Nordic pulp, paper and packaging industries. *European Environment*, *17*, 92-105. doi:10.1002/eet.

Kneller, R., & Manderson, E. (2012). Environmental regulations and innovation activity in UK manufacturing industries. *Resource and Energy Economics*, *34*(2), 211-235. doi:10.1016/j.reseneeco.2011.12.001.

Krozer, Y., & Nentjes, A. (2008). Environmental policy and innovations. *Business Strategy and the Environment*, *17*, 219-229. doi:10.1002/bse.

Krugman, P. (2010). Cómo construir una economía verde. *Negocios. El País*, pp. 4-12.

Kumar, S., & Managi, S. (2010). Sulfur dioxide allowances: Trading and technological progress. *Ecological Economics*, *69*(3), 623-631. doi:10.1016/j.ecolecon.2009.09.013.

Labandeira Villot, X., & Loureiro García, M. (2009). Apuntes sobre la investigación económica del cambio climático. *Economía y Medio Ambiente ICE*, *847*, 127-148.

Lanoie, P., Laurent, J., Johnstone, N., & Ambec, S. (2007). *Environmental Policy, Innovation and Performance: New Insights on the Porter*

Hypothesis. Working Paper. Institut National de la Recherche Agronomique, Université Pierre Mendès France.

Mazzanti, M., & Zoboli, R. (2006a). Economic instruments and induced innovation: The European policies on end-of-life vehicles. *Ecological Economics*, *58*(2), 318-337. doi:10.1016/j.ecolecon.2005.06.008.

Mazzanti, M., & Zoboli, R. (2006b). *Examining the factors influencing environmental innovations* (No. 20.2006). *Social Science Research*. Retrieved from http://www.feem.it/Feem/Pub/Publications/Wpapers/default.htm.

Mickwitz, P., Hyvattinen, H., & Kivimaa, P. (2008). The role of policy instruments in the innovation and diffusion of environmentally friendlier technologies: popular claims versus case study experiences. *Journal of Cleaner Production*, *16*(1), S162-S170. doi:10.1016/j.jclepro.2007.10.012.

Newell, R. G., Jaffe, A. B., & Stavins, R. N. (1998). *The induced innovation hypothesis and energy-saving technological change* (No. 6437). Cambridge.

Noailly, J. (2012). Improving the energy efficiency of buildings: the impact of environmental policy on technological innovation. *Energy Economics*, *34*(3), 795-806. doi:10.1016/j.eneco.2011.07.015.

OECD (2000). *Voluntary approaches for environmental policy: an assessment*. OECD Publishing. doi:http://dx.doi.org/10.1787/9789264180260-en.

Oosterhuis, F. (2006). *Innovation dynamics induced by environmental policy. Final Report*. EU Commission- DG Environment.

Popp, D., Newell, R. G., & Jaffe, A. B. (2011). *Energy, the environment and technological change*. *Handbook of the Economics of Innovation Volume 2* (1st ed., Vol. 2). Elsevier B.V. doi:10.1016/S0169-7218(10)02005-8.

Porter, M. E., & van der Linde, C. (1995). Toward a new conception of the environment-competitiveness relationship. *Journal of Economic Perspectives*, *9*(4), 97-118.

Rave, T., Goetzke, F., & Larch, M. (2011). *The determinants of environmental innovations and patenting: Germany reconsidered*. IFO Working Paper No. 97. Retrieved from: http://cesifo-group.de.

Rehfeld, K., Rennings, K., & Ziegler, A. (2007). Integrated product policy and environmental product innovations: An empirical analysis. *Ecological Economics*, *61*(1), 91-100. doi:10.1016/j.ecolecon.2006.02.003.

Rennings, K. (1998). *Towards a theory and policy of eco-innovation-Neoclassical and (Co-) Evolutionary Perspectives*. Retrieved from: http://hdl.handle.net/10419/24575.

Rennings, K. (2000). Redefining innovation - eco-innovation research and the contribution from ecological economics. *Ecological Economics*, *32*, 319-332.

Rennings, K., Ziegler, A., Ankele, K., & Hoffmann, E. (2006). The influence of different characteristics of the EU environmental management and auditing scheme on technical environmental innovations and economic performance. *Ecological Economics*, *57*(1), 45-59. doi:10.1016/j.ecolecon.2005.03.013.

Requate, T. (2005). Dynamic incentives by environmental policy instruments—a survey. *Ecological Economics*, *54*(2-3), 175-195. doi:10.1016/j.ecolecon.2004.12.028.

Rogge, K. S., & Hoffmann, V. H. (2010). The impact of the EU ETS on the sectoral innovation system for power generation technologies – Findings for Germany. *Energy Policy*, *38*(12), 7639-7652. doi:10.1016/j.enpol.2010.07.047.

Sterner, T., & Turnheim, B. (2009). Innovation and diffusion of environmental technology: Industrial NOx abatement in Sweden under refunded emission payments. *Ecological Economics*, *68*(12), 2996-3006. doi:10.1016/j.ecolecon.2009.06.028.

Taylor, M. R., Rubin, E. S., & Hounshell, D. A. (2005). Control of SO_2 emissions from power plants: A case of induced technological innovation in the U.S. *Technological Forecasting and Social Change*, *72*(6), 697-718. Retrieved from http://www.sciencedirect.com/science/article/pii/S0040162504001465.

Vollebergh, H. (2007). *Impacts of environmental policy instruments on technological change*. OECD Report.

Wagner, M. (2007). On the relationship between environmental management, environmental innovation and patenting: Evidence from German manufacturing firms. *Research Policy*, *36*(10), 1587-1602. doi:10.1016/j.respol.2007.08.004.

Wagner, M. (2008). Empirical influence of environmental management on innovation: Evidence from Europe. *Ecological Economics*, *66*(2-3), 392-402. doi:10.1016/j.ecolecon.2007.10.001.

Yarime, M. (2008). Promoting green innovation or prolonging the existing technology. *Journal of Industrial Ecology*, *11*(4), 117-139. doi:10.1162/jiec.2007.1151.