United or Divided We Stand? Perspectives on the EU's Challenges

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Environmental regulation and eco-innovation: insights from diffusion of innovations theory

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Abstract

The paper analyses the relationship between environmental regulation and environmental innovation with insights from the diffusion of innovations theory. We base the analysis on three theoretical approaches: neoclassical, evolutionary and induced innovation. The relationship is tested using a German firm-based panel and a count data model. We estimate the propensity of firms to innovate in response to five initiating factors, namely the fulfillment of existing legal requirements, expectations towards future legal requirements, financial incentives, demand for environmental innovations and self-commitment. We also check for the relevance of the interactions between policy instruments as well as the influence of internal factors and path dependency. In addition, we control for R&D intensity, the region, the sector of the company and filter for companies that account for their environmental impact. The results answer the central question concerning the design of environmental policies in order to foster innovation. Comparing a static model to a dynamic one, we show that only long term objectives and market incentives are positively associated with environmental innovation. Conventional regulatory tools, namely legally binding instruments, are not effective for triggering innovative behaviour at the firm level. Lastly, we show that the threat of future environmental regulation is a necessary condition for self-regulation.

Keywords: Porter Hypothesis, Environmental regulation, Environmental innovation, Diffusion of innovations, Count Data.
JEL: C23, H23, O31, O38, Q55.

1. Introduction

Since it was first published in 1962 by Everett M. Rogers, the diffusion of innovations theory has been the subject of numerous applications in various fields. In his theory, E.M. Rogers explains how ideas spread through the process of adoption of innovations (Rogers, 2010). The applications of this theory went beyond its original domain. In fact, while Rogers (2010) has introduced his theory by explaining how technologies and best practices are adopted and spread among farmers, the methodology proposed by the diffusion of innovations theory has been used in medical sciences (Greenhalgh et al., 2004), communication networks (Valente, 2005), marketing (Mahajan et al., 1990) or environmental innovation (Kern et al., 2005; Beise & Rennings, 2005; Lanjouw & Mody, 1996; Schwarz & Ernst, 2009) which we do as well in this paper. In 1991, Michael E. Porter published a short, yet controversial, article where he explained that stricter environmental regulation could, actually, improve business competitiveness through environmental innovation (Porter, 1991). This claim would later be known as the "Porter Hypothesis". It goes without saying that such a claim from an influential Harvard professor created a turmoil in the scientific, political and business community alike. Following this line of thought, the research in this paper is centered around the Porter Hypothesis. However, this paper limits itself to investigating the relationship between environmental regulation and environmental innovation, which is also known as the "weak" Porter Hypothesis (Mohnen & Van Leeuwen, 2015). Thus, the current paper is an addition to the scientific literature on the subject of the relationship between environmental regulation and environmental innovation based on the diffusion of innovations theory. Three policy alternatives, namely legally binding instruments, financial & market incentives, and self-regulation are compared in order to answer the following research question: which policy is more inclined to foster eco-innovation? To do so, this paper considers three theoretical approaches: the neoclassical, the evolutionary

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and the induced innovation theory. The relationship between environmental regulation and environmental innovation is tested using a German firm-based panel data collected by the Centre for European Economic Research in Mannheim (ZEW[1]) which will allow us to study the innovative behaviour of businesses over time. As noted by Jaffe & Palmer (1997) and more recently by Lanoie et al. (2008), the lack of dynamics is one of the recurrent shortcomings in testing the Porter Hypothesis. Accordingly, a dynamic count data model is compared to a static model in order to estimate the propensity of firms to innovate in response to a set of initiating factors for environmental innovation, namely the fulfilment of existing legal requirements, expectations towards future legal requirements, public funding, demand for environmental innovations and self-commitment (cf. figure 1). In addition, we control for research and development intensity and the size of the company. These factors are suspected to be responsible for an important omitted-variable bias causing model misspecification (Griliches, 1979; McWilliams & Siegel, 2000). We also control for the region (eastern/western Germany) and the potential industry bias by using 23 sectoral dummies, and filter for companies that account for their environmental impact (Wagner, 2010; Busch & Hoffmann, 2011). The remainder of this paper is divided into five sections, a review of the relevant literature on the diffusion of innovations theory and the relationship between environmental regulation and environmental innovation, followed by a formulation of the hypotheses to be tested, the methodology used for the empirical model, the results and a discussion of these results.

2. Literature review

Measuring eco-innovation is still subject to a debate in academia with different measures such as research & development expenditures, patents or eco-efficiency performance (Arundel & Kemp, 2009). In this paper we rely on the definition of environmental innovation given by Beise & Rennings (2005). The authors pointed to the fact that an innovation that has been developed without the specific goal of either reducing or avoiding environmental harm is still considered as eco-innovation. In fact, in many cases the decision to eco-innovate is motivated by economic objectives rather than environmental considerations. Accordingly, limiting the dependent variable to innovations with the explicit aim of reducing the environmental impact might exclude a number of projects that do reduce environmental harm but were not necessarily designed with the aim of doing so (OECD, 2009). In fact, Calleja et al. (2004) found very few distinctions between "normal" innovation and eco-innovation when it comes to the factors affecting its adoption and diffusion. The most notable one is the distinction between end-of-pipe and process or product eco-innovation. More specifically, Rothenberg & Zyglidopoulos (2003) explain that when it come to policy: "in order to encourage the adoption of environmental innovations, one can also focus on enhancing industries overall ability to adopt new technologies in general . . . therefore, it might be less important to focus on environmental technologies than to increase regulatory flexibility so as not to impede technology adoption" (Rothenberg & Zyglidopoulos, 2003, p. 15). Thus, suggesting that the normal innovation drivers are just as important for the adoption and diffusion of eco-innovation and that innovative businesses, in general, are more likely to eco-innovate, as well. Moreover, Del Río (2009) explained that environmental technological change occurs at three different stages: invention, innovation and diffusion. Limiting the dependent variable to patents for instance could exclude innovation projects at earlier stages.

Stoneman & Battisti (2010) define the diffusion of innovations as the "relative" change in the market in terms of ownership and usage of a new technology. They emphasize the importance of the market in their definition implying two sides (innovators and users) in the diffusion process. According to the authors, the concept of the "newness" of a technology is relative as well. They distinguished between two levels: the world and the firm, thus allowing for a differentiation between global and local innovation. Moreover, Stoneman & Battisti (2010) listed four levels of diffusion, depending on the aggregation level: international, for technologies imported for other countries, national, for technologies diffused between different industries, inter-firm, when technologies are diffused between firms within the same industry, and intra-firm, for technologies diffused within a single firm. Because of the technological externalities in the process of diffusion of a new technology, government intervention is justified. Indeed, due to the spillover effect and the fact that some or all aspects of eco-innovation become accessible to other businesses, a market failure appears preventing the innovator from appropriating all the benefits of the new technology, unless protected by an adequate regulatory framework (Stoneman & Battisti, 2010; Cohen & Levinthal, 1989). In their article, Murphy & Gouldson (2000) clearly state that with increased awareness of ecological risks, regulators have responded with a series of regulatory reforms arguing that an ecological modernization can result in both economic and environmental benefits. The authors commented on that claim by pointing out the lack of evidence on the potential of policies to foster ecological innovation. Murphy & Gouldson (2000) added that if regulators aim at mitigating ecological impact without undermining economic growth, they would have to resort to "innovative policy instruments and approaches to replace the traditional understanding of the regulation of industry, particularly through the incentivisation of environmental improvement"(Murphy & Gouldson, 2000, p. 35). In that sense, the dynamic nature of innovation coupled with scale

[1]ZEW stands for Zentrum für Europäische Wirtschaftsforschung.

and learning effects results in improved quality and reduced economic costs over time (Murphy & Gouldson, 2000). Thus, the economic efficiency of a new innovation is positively associated with its diffusion. When studying the case of the Integrated Pollution Control (IPC) of the Environmental Protection Act (1990) in England and Wales, Murphy & Gouldson (2000) noticed that businesses would rather consider end-of-pipe solutions, instead of radical change in their process, to meet regulatory standards such as emission standards with hardly any innovation at all. However, they would resort to abatement technologies (process innovation) when expecting increasingly stringent long-term environmental objectives. For the former solution, the argument of the interviewed managers was the relative lower costs and the ease of implementation to the existing facilities with no expectations of economic benefits aside from avoiding any penalties as a result of environmental inspections. For the latter solution, the argument was more of a strategic orientation with a pro-active move towards increasingly stringent environmental regulation and social concerns, rather than a reactive compliance to existing regulation. In addition, businesses saw tangible benefits for eco-innovation in the form of cost savings, productivity improvements and customer satisfaction. However, this option entails higher costs and lower flexibility and required more time to implement. In the same line of thought, Fisher & Freudenburg (2001) described ecological modernization as being twofold. They explain that in order to successfully transition to a more sustainable economy, policies need to be both economically and politically feasible with businesses committed to ecological change and politics ensuring environmental protection and supporting eco-innovation. Thus, in order to meet both expectations, new forms of political interventions need to be used. More recently, Huber (2008) explained that environmental regulation is a necessary condition for eco-innovation. On the one hand, the author stated that "it is stringent regulatory innovation which paves the way for technological environmental innovations" (Huber, 2008, p. 362). On the other hand, Huber (2008) explained that the type of regulation used is critical. In effect, if the objective is to foster innovation, then performance standards are to be preferred to technology standards. Similarly, Johnstone (2005) argued in favour of performance-based measures rather than standards-based regulation. For the latter option, the author stressed the absence of incentives to go beyond the standard, while with the former, regulation is more likely to lead to new technologies that might surpass the environmental standard more efficiently and cost effectively. However, taking into account the pace of environmental deterioration, which is faster than the ecological modernization, command and control regulation is, sometimes, necessary. Huber (2008) suggests, in that case, to accompany performance-based standards with market-based instruments and stringent long-term objectives. Similarly, Nordhaus (2011) distinguished between standard-based and performance-based regulation. According to the author, both are considered as command and control since they set the objective to achieve, however standard-based regulation specifies the technology to use, while performance-based regulation gives businesses the freedom to choose the technology to use in order to meet the regulatory objective. The authors illustrated his claim using CO_2 emissions as an example. The regulator could decide to impose a specific technology, Carbon Capture and Sequestration (CCS) for instance, in order to reduce the level of pollution. Under such circumstances, businesses would have to show both capture and ultimate storage of CO_2 emissions and risk penalties if the legal requirements are not satisfied (Nordhaus, 2011). This is the case of standard-based regulation. Alternatively, the regulator could establish a performance standard that would limit the emissions allowed per unit of production. Under such circumstances, businesses would only have to show that they have met the legal requirements either by using CCS or any other technology and risk penalties if they do not comply with the legal boundary. Notwithstanding the neoclassic theory, other analytical and theoretical approaches have been used in order to explain the relationship between policy and innovation. For instance, the evolutionary economics approach exploring the interactions and the feedback applicable to eco-innovation policy (Rennings, 1998). The induced innovation theory (Jaffe et al., 2003; Ruttan, 2002) is another approach exploring the endogeneity of innovation, the path dependency and the internal motives. Both the evolutionary and the induced innovation approach together with the neoclassical approach will be tested empirically.

3. Hypotheses development

3.1. Neoclassical approach

The neoclassic theory (Rennings, 2000) analysing the marginal effect of policy instruments on eco-innovation. Based on the literature review, five hypotheses are formulated to be later tested by the model empirically with the objective of studying the marginal effect of different policy instruments on eco-innovation.

3.1.1. Legally binding instruments

In order to study the marginal effect of legally binding instruments we distinguish between existing environmental regulation and the expectations towards future environmental regulation.

Evidence from the literature show that technology-based regulation is not as effective as market-based regulation if the aim is to foster innovation dynamically (Johnstone, 2005; Huber, 2008). In reality, a standard has to be both ambitious enough to foster innovation while remaining realistically feasible by businesses. The balance between these two objectives is no easy task. Another limitation is the fact that however ambitious a standard is, if not revised dynamically, once it is met by businesses there is

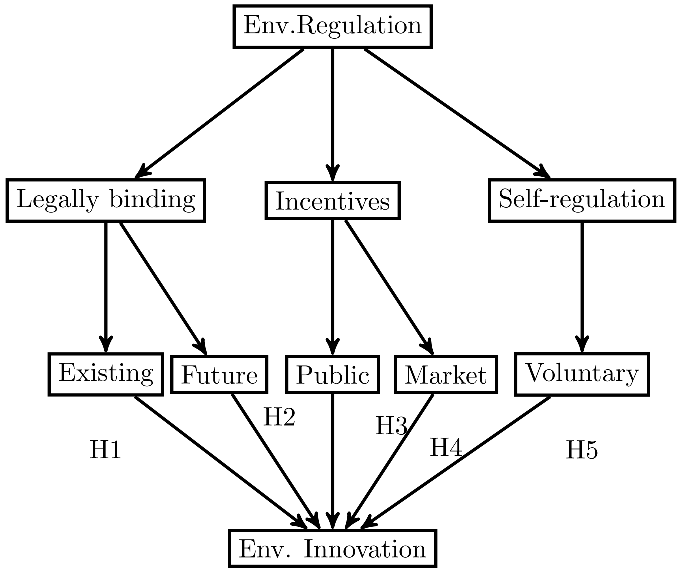

Figure 1: Theoretical model

no incentive to go beyond the regulatory requirement, thus limiting the prospect of future technological innovation. In addition, such instruments limit the technological choices to achieve the regulatory objective, and therefore remove the incentive to develop new ways of reducing environmental harm (Jaffe & Stavins, 1995). Moreover, Jaffe & Stavins (1995) warn against a counter-effect of such regulation. The authors argue that innovative businesses might even refrain from developing new technologies fearing more rigorous performance standards in the future.

Taxes are another type of legally binding instruments. Regulators design eco-taxes such that their value reflects the cost of the environmental harm caused by business, thus internalizing the value of the negative environmental externality originated by firms subject to these taxes (Andersen & Sprenger, 2000). In line with the previous arguments, Frondel et al. (2004) found that although positively associated with the adoption of new technologies, legally binding regulatory measures tend to favour end-of-pipe solutions rather than process innovation. Nevertheless, the authors noted that taxes, for instance, are necessary when targeting environmental harm that cannot be reduced by process innovation (such as diesel emissions). Otherwise, policies should be designed to stimulate investments in cleaner process and product innovation. Accordingly, regulations should appropriately alleviate the obstacles faced by eco-innovators rather than impose technology standards that can only be met through end-of-pipe measures (Frondel et al., 2004). Similarly, Krysiak (2011) showed that standard-based regulation and taxes do not foster innovation but rather encourage the adoption of the least-costly available technology thus leading to a lock-in into a "possibly inferior technology" (Del Río, 2014).

Based on these theoretical arguments, we hypothesize that legally binding instruments, alone, are ineffective in fostering innovation. That being said, with increasing public concern, regulators, often, resort to command and control regulation in order to have a convergence towards a level of pollution deemed more acceptable than the current level.

Hypothesis 1 *Existing regulation does not foster innovation.*

Unlike technology-specific regulation, performance-based regulation sets long-term objectives, thus creating a dynamic effect with clear objectives over a known time-horizon. Performance-based regulation is defined as a type of regulation which sets the objectives to reach with minimal technical details on the means to achieve them (Queensland Government, 2006; Coglianese et al., 2004; Guerin et al., 2003; Lowry, 2002). Such regulation is, often, featured with multiyear plans and long-term objectives that are systematically updated (Sappington et al., 2001). The main departure from standards-based regulation in such regulation is the presence of a "beyond compliance" incentive for businesses (Zarker & Kerr, 2008). In effect, Calleja & Delgado (2008) explain that in order for such "performance targets" to set a clear signal they should be based on a long-term and progressive guiding vision of the economy. Another difference between technology-based regulation and performance-based lies in the fact that businesses are free to choose the technology to adopt in order to achieve the objective, and are encouraged to discover new, more efficient and effective, technologies to achieve the regulatory objectives.

In addition, Del Río et al. (2010) explain that a long-term vision grants firms more flexibility to comply with stringent objectives. Thus, providing a framework more inclined to the development and the diffusion of radical eco-innovation. However, while too much certainty would not be enough of a stimulus, too much uncertainty would inhibit investment in eco-innovation (Ashford, 1993). Accordingly, a right balance between the clarity in the policy vision and the consistency in the signal of increasingly stringent environmental targets need to be achieved in order to meet the intended goal of fostering eco-innovation. Therefore, the theoretical arguments seem to agree with the hypothesis that expectations toward future regulation do foster innovation.

Hypothesis 2 *Signal of future regulation does foster innovation.*

3.1.2. Incentives for eco-innovation

In order to study the marginal effect of incentives for eco-innovation we distinguish between public financial incentives, such as subsidies, and the market incentives, such as demand for green products.

In contrast to command and control regulation, which is considered direct regulation, financial policy incentives are considered indirect regulation. Economic policy instruments include, but are not limited to, subsidies, taxes, property rights, tradable permits and aim to reinstate the full-cost of an activity and align it with the social cost (Opschoor, 1995). Financial incentives are limited to the different forms of subsidies such as loans, guarantees, interest rate subsidies, ... (European Commission, 2014). The objective of such policy instruments is to internalize the value of the environmental externality (Andersen & Sprenger, 2000). In the case of a subsidy for instance, the value should reflect the positive spillover of eco-innovation. Alternatively, the regulator could decide to encourage eco-innovation in the form of a tax credits for avoided emission as a financial incentive (Nordhaus, 2011). According to the European Environment Agency (2006), financial policy instruments give businesses the freedom to choose, or develop, the best technology to achieve the established regulatory level of environmental protection. Thus, the objective of such a tool is to lift the barriers faced by eco-innovators rather than to penalise polluters. Accordingly, these measures are more in line with the objective of a sustainable transition (Del Río et al., 2010). However, Andersen & Sprenger (2000) warn against the perverse effect of such instruments. In the case of subsidies, the authors noted that the lack of an incentive and reward system led to reduced levels of investment in pollution reduction technologies and favoured end-of-pipe solutions[2].

The theoretical arguments do not seem to provide a clear-cut to whether such instruments foster or hinder innovation. Thus, we can not lean towards neither a positive nor a negative association between public financial incentives and innovation.

Hypothesis 3 *Public financial incentives foster innovation.*

Popp et al. (2010) define market-based instruments as "mechanisms that encourage behaviour through market signals rather than through explicit directives regarding pollution-control levels or methods." In that sense, market-based policies are considered indirect regulation. In other words, businesses are free to choose the way to achieve the regulatory objectives. The main characteristic of market-based incentives is the fact that they "harness the market forces" (Stavins, 1995) rather than influence the price or quantities of the market (Ecorys, 2011). A typology of market-based policy instruments is given in figure 2.

Rennings (2000) refers to market incentives as the "technology push factors" and the "market pull factors". In fact, a new technology will be diffused if it is found to be more efficient and cost effective, thus creating a market. In the same manner, if there is a demand for green products then a market for eco-innovations will be created, thus fostering innovation. In that sense, policies should be designed in a way that they stimulate such market forces.

In a report for the European Commission, Ecorys (2011) refers to these market-based incentives as "market friction instruments" that ameliorate the market conditions by improving information flows. Whitten et al. (2003) provided a comprehensive list of such instruments. They listed, among other tools, the reduction of market barriers for eco-innovative products, education programs for consumers, research programs with market applications, eco-labelling and information disclosure. However, the authors commented that such instruments have a less certain output and take longer than other market-based instruments to show results.

Based on these theoretical arguments, it is quite clear that such incentives will foster innovation dynamically and allow businesses to go well beyond compliance objectives.

Hypothesis 4 *Market-based incentives do foster innovation.*

3.1.3. Self-regulation

In order to study the marginal effect of self-commitment for eco-innovation we consider the relevance of instruments with no legally binding force such as sectoral voluntary agreements or Environmental Management Systems. Many researchers have observed that unregulated businesses would rarely decide to invest in green technologies (Hahn & Stavins, 1991). This is explained by the fact that with no regulation businesses would not have to bear the cost of their negative environmental externalities. At the same time, if a business makes the decision to eco-innovate the "double-externality problem" (Rennings, 2000) will reduce its incentive to take such a decision. In fact, the peculiarity of eco-innovation resides in the fact that the environment is a non-excludable and non-rivalrous public good (Marginson, 2007). As such, while the benefits of eco-innovation are shared by all the society, the sole bearer of the costs is the innovator (Beise & Rennings, 2005). Another reason

[2]The authors illustrate with the case of the Spanish agricultural sector

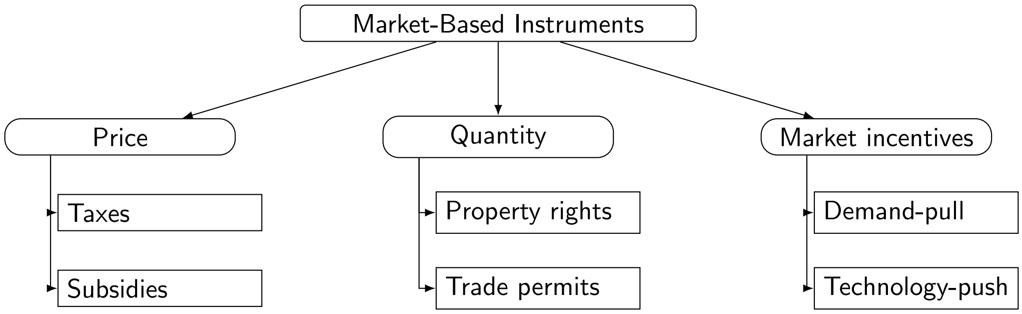

Figure 2: Typology of market-based policy instruments
Source: Adapted from Whitten et al. (2003)

businesses would not invest in eco-innovation, if left to decide for themselves, is simply because other investment options are, often, more financially rewarding (Fiorino, 2006). Taking all these points into account, regulators are summoned to intervene in order to achieve socially efficient levels of environmental protection. In that sense, policies should tackle the problem of market failures in terms of positive and negative externalities as well as financial attractiveness of environmentally friendly technologies.
These theoretical arguments allow us to formulate the hypothesis that self-commitment of businesses will not suffice to foster innovation.

Hypothesis 5 *Regulatory intervention is necessary to foster innovation.*

3.2. Evolutionary approach

The evolutionary process encompasses all supporting institutions and factors affecting the "green" market such as policies, technical standards, voluntary agreements or demand for green products (Andersen, 2010). Del Río et al. (2010) added that drivers of eco-innovation are not isolated from one another but are rather in interaction with each other. These policy mixes could lead to synergistic effects where consistent instruments are associated in a "smart" design in order to avoid the problems caused by the layering of various policy instruments. By contrast, these policy mixes could also cause negative conflicts when the policy portfolio is composed of incoherent instruments resulting in suboptimal situations due to redundancy for instance (Howlett & del Rio, 2015). The multiplicity of the barriers faced by eco-innovators and their interrelatedness requires the use of a combination of different policy instruments, simultaneously, in order to address the different aspects of environmental technological change in an integrated fashion (Del Río et al., 2010).
Based on the literature review, we consider the interactions between the different policy options to better reflect the evolutionary approach of the drivers of eco-innovation.
Self-regulation instruments are based on consent, incentives and coercion (Chappin et al., 2009). However, although necessary for stimulating eco-innovation, the coercive instruments are not sufficient and need to be combined with a threat of stringent future regulation to effectively foster radical eco-innovative (Combining the stick and the carrot) (Del Río et al., 2010). Otherwise, this policy choice would only lead businesses to do "business as usual" and not necessarily activities that they would not engage in otherwise (Jaffe et al., 2003). In line with the previous arguments, Blackman et al. (2010) found that if businesses are under pressure from regulators, their participation in voluntary agreements is more likely to happen. In his book, Fiorino (2006) took the Dutch energy benchmarking program as an example to explain how the expectation of a more stringent future regulation allowed to increase the number of businesses participating. The program offered businesses the choice of either demonstrating that they belong to the top 10% in term of energy efficiency, or risk facing strict environmental regulation. Likewise, Brouhle et al. (2005) explained that the success of voluntary instruments is intricately linked to the threat of collectively liability and stricter environmental regulation in case of failure in meeting the environmental target specified in the voluntary agreement, regardless of the individual performance of each business.
Based on these arguments, we expect the combination of self-regulation and the expectation of future environmental regulation to foster eco-innovation to the drivers of eco-innovation.

Hypothesis 6 *Self-regulation does not foster innovation unless coupled with a signal of future environmental regulation.*

3.3. Induced innovation approach

The induced innovation approach is based on the fact that the prospect of producing profitable new products and processes is sufficient to motivate businesses to engage in research & development activities (Jaffe et al., 2003). More specifically, the strategic motivation to engage in environmental R&D would be, on the one hand, a "demand-pull" for green goods, services or processes, and on the other hand, the cost savings thanks to more efficient processes, recycling or lower factor costs (such as labour). Ruttan (1997) adds that the path dependency is a complementary rather than an alternative model explaining the

factors influencing innovation, which will be considered in the empirical application.
Based on the literature review, we consider path dependency and internal factors as drivers for innovation to better reflect the induced innovation approach.
To explain the path dependency in eco-innovation, Andersen (2010) referred to its underlying "cognitive roots". The author explained that eco-innovation is first and foremost: "a learning process involving the creation of new understandings, values, capabilities and search rules, hence the suggestion of situation eco-innovation as part of a move towards the green learning economy" (Andersen, 2010, p. 15). In their paper, Wagner & Llerena (2011) came to the conclusion that eco-innovation is a path dependent activity that is determined by historic processes. The authors illustrated their claim using the consultations between the European Commission and the European car industry about CO_2 emission targets. Due to their historical heritage of producing small cars, the French and Italian manufacturers were more resistant to a sectoral agreement than other car manufacturers. On the other hand, Könnölä & Unruh (2007) based their definition of path dependency in the context of eco-innovation on the "Lock-in theory" emphasizing the fact that most innovations are based on past knowledge and require to be adapted to current situations in order to be successfully diffused. Thus, regulators are summoned to intervene in order to break the path dependency of businesses locked-in "old dirty technologies" (Veugelers, 2012). Similarly, Aghion et al. (2012) recognised the existence of path dependency in the current industry and called for public intervention in order to break it and "redirect" innovation activities from "dirty" to "clean" technologies. To do so, the authors studied the auto industry innovations, distinguishing between clean and dirty patents across 80 countries over several decades[3]. They came to the conclusion that policies should act in such a way that cleaner products can be "perceived as substitutes for dirty products by consumers" (Aghion et al., 2012). By contrast, Woiceshyn & Eriksson (2014) provided evidence against the dominant idea on the path dependency of innovation in the literature. They showed that innovative behaviour does not necessarily lock-in as a result of positive change. They explain that the attitude towards innovation can change both incrementally and radically regardless of the past situation, even in the absence of external factors. However, they came to the conclusion that in such cases innovation policy would need to be adapted. They argued that the regulator should attempt to enable innovation instead of controlling all its aspects, thus encouraging technological innovation (Woiceshyn & Eriksson, 2014).
Based on these arguments, we expect eco-innovation to be path dependent and positively associated with past innovative behaviour.

Hypothesis 7 *Eco-innovation is path dependent.*

When studying the factors impacting eco-innovation, Demirel & Kesidou (2011) found that cost savings are an important driver for the most advanced type of eco-innovations. In fact, the authors found that together with regulatory pressure, the prospect of cost savings stimulates investment in environmental research & development. In addition, Frondel et al. (2004) found that the expectation of cost savings tends to favour the adoption of process-integrated technologies rather than end-of-pipe options. These more efficient processes may then lead to additional cost savings that can be, in turn, used to further invest in eco-innovations (Demirel & Kesidou, 2011). Similarly, Ghisetti & Rennings (2014) came to the conclusion that businesses would voluntarily adopt environmental innovations if they perceive it as an opportunity for cost savings instead of a cost-burden. Finally, when studying the determinants of eco-innovations, Horbach et al. (2012) empirically confirmed, the widespread conception in literature that cost savings do indeed trigger eco-innovation.
Accordingly, since it seems to be widely agreed in the literature and confirmed by numerous empirical applications, we do not see any reason why cost savings would not encourage eco-innovation.

Hypothesis 8 *Cost savings encourage eco-innovation.*

4. Methods

4.1. Methodology

Many studies concerning the Porter Hypothesis have come to the conclusion that there is no such thing as a win-win solution when it comes to environmental regulation, eco-innovation and business competitiveness (Ambec & Lanoie, 2008). Those studies claimed that there are no "low-hanging fruits" to be picked, and if they did exist businesses would not need any governmental intervention, in the form of regulation for instance, to seize such opportunities (Ambec & Barla, 2006). However, Ambec & Lanoie (2008) commented on those results by pointing out that the methodologies used have been lacking dynamics, among other things such as controlling for R&D intensity or the size and the sector of the business (McWilliams & Siegel, 2000; Wagner, 2010). Indeed, the original claim of the Porter Hypothesis is that stricter environmental regulation would foster eco-innovation, which will in turn either, or both, reduce the costs and/or increase the revenues of businesses subject to stringent environmental regulation, and thus enhance their competitiveness. Ambec & Lanoie (2008) noted that such a process requires time, while many researchers who have rejected the Porter Hypothesis studied the effect of regulation on innovation and productivity, or business performances, on the same period. The authors added that when Lanoie et al. (2008) allowed for a lag in time, they found that stringent regulation had a greater impact on productivity gains compared to a static model. Following those arguments, we

[3] Based on patents from 1978 to 2005

compare a static count data model to a dynamic one in order to test the relationship between environmental regulation and the diffusion of innovations. This choice is due to the nature of the dependent variable (total number of innovation projects). In effect, the total number of innovation projects is a variable that takes non-negative integer values. In addition, the period of study is relatively short and the number of observation is large. Under these conditions, Cameron & Trivedi (2013) explain that the negative binomial model is necessary, especially if the count variable is incomplete due to truncation for instance, which is the case for the total number of innovation projects in the ZEW survey. In order to allow for time dependency, the lagged values of the dependent variable are added to the model as a regressor.

The formal specification of the model is given by the following equations (Bai, 2013), (Moral-Benito, 2013):

$$y_{it} = \rho y_{it-1} + x_{it}^{'}\beta + w_{i}^{'}\gamma + \nu_{it} \tag{1}$$

$$E(\nu_{it}|{y_i}^{t-1}, {x_i}^{t}, w_i) = 0 \qquad (t = 1, ..., T)(i = 1, ..., N) \tag{2}$$

Where:
y_{it-1} is a vector of the lagged values of the dependent variable.
x_{it} is a vector of time-varying variables.
w_i is a vector of time-invariant variables.
ν_{it} is the time-varying error term.
The objective is to assess the effect of different policy options on the innovation behaviour of businesses. In order to avoid a misspecification in this relationship it is necessary to control for other factors that may affect the innovative behaviour of businesses.

For the neoclassical approach, the following empirical model is specified:.

$$TotInno = f(IFs) + Control\ variables + \epsilon \tag{3}$$

Where:
TotInno is the dependent variable measuring the total number of innovation projects during the last three years.
IFs is the five different variables representing the initiating factors of environmental innovation.
Control variables:
R&D is the R&D intensity of the company measured by the total R&D expenditures as a share of the turnover (values over 15% are truncated).
EMS is a dummy variable that filters companies that account for their environmental impact.
Size is the natural logarithm of the number of full-time employees.
Region is a dummy variable controlling for the region of the company (Eastern/western Germany).
Sector is a categorical variable accounting for the sector of the company.

For the evolutionary approach, the following empirical model is specified, keeping the same dependent and control variables:.

$$TotInno = f(Interactions) + Control\ variables + \epsilon \tag{4}$$

Where:
Interactions variables include the four interactions between existing legally binding regulation, expectations towards future regulation, public funding, market demand for green innovation, on the one hand, and self-commitment as an initiating factor for eco-innovation, on the other hand.

For the induced innovation approach, the following empirical model is specified, keeping the same dependent and control variables:.

$$\begin{aligned} TotInno = f(&Path\ depdendency, Cost\ savings) \\ &+ Control\ variables + \epsilon \end{aligned} \tag{5}$$

Where:
Path dependency is a dummy variable accounting for past innovative behaviour.
Cost savings is a categorical variable representing the degree of relevance of cost savings as an innovation goal for the previous period.

The theoretical model tested is represented in figure 1. Environmental regulation is linked to environmental innovation through the different policy alternatives. The marginal effect of each policy instrument in fostering innovation is estimated. Practically, three alternatives are compared: legally binding instruments, incentives for eco-innovation and self-regulation. A distinction between existing and expected future regulation is made. Both forms of incentives for eco-innovation: public funding and market demand are expected to be more effective than legally binding instruments since they create continuous and dynamic incentives. Finally, if left unregulated, businesses are not expected to eco-innovation. In other words, while strategic self-commitment and voluntary agreements have led to encouraging results when adopted, if the number of participants is too few then the expected effect will not be significant (Nordhaus & Danish, 2005; Gardiner & Jacobson, 2002).

4.2. Data set

In order to test the hypotheses listed in section 3 we rely on a firm-based panel data collected by the Centre for European Economic Research in Mannheim. The ZEW is responsible for annual surveys on the innovative behaviour of the German economy (ZEW, 2014). The Mannheim Innovation Panel (MIP) represents the German contribution to the Community Innovation Surveys (CIS) coordinated by the European Commission. The ZEW started sending surveys in 1993 to the same firms (with at least 5 employees) on an annual basis. Every second year, the panel sample is updated in order to account for businesses that left the market due to firm closures or mergers. The gross sample is stratified by sector, size and region (Peters & Rammer, 2013). In fact, various industries are represented to reflect the German economy. The sectors surveyed range from mining, manufacturing, energy and water supply, construction, trade, financial intermediation, transport to business-oriented services. The complete list is given in table 1.

The sector affiliation of firms surveyed in the MIP can be identified through the Nomenclature of Economic Activities code or NACE code (French term "Nomenclature statistique des Activités économiques dans la Communauté Européenne") (Eurostat, 2008). The sectors excluded from the data set are: agriculture, forestry and fishing, public administration, health, education, and personal and cultural services. The response rate varies from year to year, for example in 2010 from a gross sample of 24000 firms, more than 6000 firms answered the written questionnaire (Gottschalk, 2013). The data sets are "factually anonymized", meaning that it is impossible to identify or draw conclusions about an individual company from the provided information without investing an extensive amount of time and money (ZEW, 2014). For example, instead of recording the absolute value for the variables of a company, the value of all the variables is multiplied by a firm-specific time-invariant constant random number. This way, even though the turnover and the number of employees of a company are not expressed in absolute value the ratio of the two variables remains the same as with absolute values. According to Peters & Rammer (2013), the main advantage of the Mannheim Innovation Panel lies in the fact that it allows to shed some light on the innovative behaviour of businesses. Indeed, the dynamic perspective on innovation panel data allows to explain why some firms innovate persistently while others do so discontinuously or completely refrain form innovating. As noted by Rexhäuser & Rammer (2014), German data are ideal for studying the relationship between regulation and innovation since Germany is one of the pioneers in strict environmental policies which make the data particularity adapted to test the hypotheses formulated in section 3. As a matter of fact, the first environmental legislation dates back to 1969 in West Germany followed by increasingly ambitious environmental policies such as the Emission Control Act, the German Energy Conservation Act (Energieeinsparungsgesetz), and more recently the Renewable Energies Act (Erneuerbare Energie-Wärmegesetz) (Richter & Johnke, 2004; Lah, 2009; Iwulska, 2012; Bauermann, 2016).

The main data set was collected in 2008 and includes a set of questions on environmental innovations and initiating factors of environmental innovation necessary for the hypotheses tested in this paper. In order to allow for dynamics, three yearly data sets were merged in order to constitute the panel dataset. The dependent variable used is the total number of innovation projects. To collect the data on this variable, businesses had to answer the following question: What was the total number of innovation projects (including R&D projects) carried out in your enterprise from 2010 to 2012? (newly started, ended or still ongoing projects). This variable is ideal to study the phenomenon of the diffusion of innovations. As noted by Meade & Islam (2006), two representations of innovation diffusion have been used in the modelling and forecasting of this phenomenon: the cumulative adoption of innovation and the period-by-period adoption. The curves of the two representations are shown in figure 3. In this model, the cumulative adoption is of particular interest in order to study the innovative behaviour of businesses in response to a set of initiating factors, dynamically. The dependent variable is truncated in order to prevent recognition of firms on the basis of large values of innovation projects. The upper limit as shown in the descriptive statistics table (2) is 1500 projects during the last three years. This truncation is helpful from an empirical point of view since it reduces the large disparities that might exist when comparing small businesses to large ones[4]. Thus, we do not see a necessity for dividing this value by the number of employees for instance.

In addition to the lagged values of the dependent variable (total number of innovation projects from 2008 to 2010), the main explanatory variables used are the five environmental innovation initiating factors, namely the fulfilment of existing legal requirements, expectations towards future legal requirements, public funding, demand for environmental innovations and self-commitment. To collect the data on these variables, businesses had to answer the following question: From 2006 to 2008, did your enterprise introduce an environmental innovation in response to:

- Existing environmental regulations (including taxes on pollution).
- Environmental regulations that you expected to be introduced in the future (including taxes on pollution).
- Availability of government grants, subsidies or other financial incentives for environmental innovations.
- Current or expected market demand from your customers for environmental innovations.
- Voluntary codes or agreements for environmental good practice within your sector.

We choose to use the lagged values for all policy-oriented variables in order to avoid the problem of reverse causality. In other words, taking into account the impact of regulation on innovation, we do not exclude the fact that innovation can in turn influence regulation. However, by using lagged values for the explanatory variables we avoid such

[4] We control for the size of the firm in using the natural logarithm of the number of full-time employees.

Table 1: MIP industry sectors

Sector	Description
1	Mining
2	Food/Tobacco
3	Textiles
4	Wood/Paper
5	Chemicals
6	Plastics
7	Glass/Ceramics
8	Metals
9	Electrical equipment
10	Machinery
11	Retail/Automobile
12	Furniture /Toys/Medical technology/Maintenance
13	Energy / Water
14	Wholesale
15	Transport equipment/Postal Service
16	Medical services
17	IT/Telecommunications
18	Banking/ insurance
19	Technical services/R&D services
20	Consulting/Advertisement
21	Firm-related services
22	Apartments/Rental
23	Others

Source: Adapted from ZEW (2014)

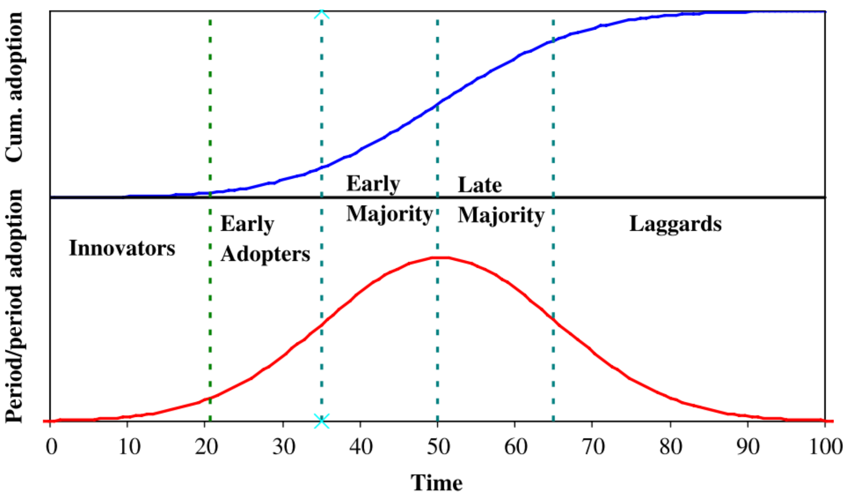

Figure 3: Diffusion of innovation
Source: Meade & Islam (2006)

interference since current innovation can not influence past regulation while the opposite is possible. Therefore we only account for the marginal effect of past regulation on innovation. Finally, in his empirical review of the determinants for eco-innovation, Del Río (2009) summarised the relevant factors for businesses to engage in environmental innovation in three categories: internal (such as financial resources), external (such as regulation) and technical (such as the cost reduction of technology). In addition, in their review of the literature, Del Río et al. (2016) noted that most of the empirical studies included the following variables in their models: regulation, size, sectoral dummies and environmental management systems. Accordingly, we control for research and development intensity

Table 2: Descriptive statistics of the estimation sample

Variable	Mean	Std. Dev.	Min.	Max.
TotInno	6.142	12.490	0	100
Legally binding	0.176	0.381	0	1
Future-reg	0.162	0.368	0	1
Financial incentives	0.059	0.237	0	1
Market incentives	0.165	0.372	0	1
Self-regulation	0.166	0.372	0	1
Path dependency	0.578	0.494	0	1
Cost savings	0.846	1.099	0	3
R&D	0.013	0.034	0	0.25
EMS	0.859	0.347	0	1
Size	3.517	1.61	0.005	13.349
Region	0.330	0.470	0	1
Sector	11.979	6.234	1	23

(Griliches, 1979; McWilliams & Siegel, 2000) and the size of the company. These factors are suspected to be responsible for an important omitted-variable bias causing model misspecification. We also control for the region (eastern/western Germany) and the potential industry bias by using 23 sectoral dummies (Wagner, 2010; Busch & Hoffmann, 2011). In addition, a filter is applied to identify environmentally friendly businesses that have set-up an environmental management system. To do so, a dummy variable is used corresponding to the following question: Does your enterprise have procedures in place to regularly identify and reduce your enterprise's environmental impacts? (For example preparing environmental audits, setting environmental performance goals, ISO 14001 certification,...).

Moreover, in order to better reflect the evolutionary approach, we create four interaction variables between self-regulation and the other fours instruments. Finally, in order to represent the induced innovation approach, we create a dummy for path dependency which takes 1 as a value if the firm had at least one innovation project during the previous period and zero otherwise. We also include a categorical variable representing cost savings as an innovation goal during the previous period (2006-2008). The variable takes 4 values from 0 to 3 (0: none, 1: low, 2: medium and 3: high).

5. Results

The results support the hypotheses formulated in section 3. The estimates give the predicted number of events on the margin, evaluated at sample means. The estimation sample includes an unbalanced panel of 1605 companies, in 23 different sectors over a period of 5 years (2006-2011). Understandingly, the number of observation drops when we allow for dynamics. The estimation results are summarised in table 3.

Based on the neoclassical approach studying the marginal effectiveness of different policy instruments the estimation results show that: Firstly, the coefficients of the fulfilment of legal requirements (legally binding instruments) and the public funding (financial incentives) are statistically insignificant suggesting no association with innovation. Secondly, the coefficient of the expectation towards future requirements (future regulation) and the demand for green products (market incentives) are as expected positive and statistically significant. Lastly, self-commitment (self regulation) was not correlated with innovation. In terms of interpretations, the statistical software allows for reporting the exponentiated coefficients rather than the coefficients. For the negative binomial model, exponentiated coefficients have the interpretation of incidence rate ratios (Stata Manual, 2013). The Incidence Rate Ratios (IRRs) of the statistically significant coefficients are reported in table 4. They allow us to appreciate the relative change in the total number of innovation projects if the initiating factor is relevant for the company compared to a company that does not consider the factor as an initiator of environmental innovation, *ceteris paribus.* Among the five initiating factors,the only two that have statistically significant coefficients are future regulation and market incentives. The first IIR represents the estimated rate ratio when comparing businesses engaging in innovation in response to their expectations towards future environmental regulation compared to businesses that considered this factor as irrelevant in their decision to innovate. While holding the other variables constant in the model. This initiating factor is expected to have an incidence rate for the total number of innovation projects of 1.317 (an increase of 31.7%). Similarly, current or expected market demand from customers for environmental innovations is expected to have an estimated incidence rate for the total number of innovation projects of 1.304 (an increase of 30.4%) for businesses recognizing these factors as relevant for their decision to innovate, all other things being equal. Based on the evolutionary approach of the determinants

Table 3: Estimation results

TotInno	Neoclassical	Evolutionary	Induced innovation	Dynamic
L.TotInno				0.0222***
Legally binding	-0.0132			-0.0588
Future-reg	0.275**			0.269**
Financial incentives	-0.00893			0.00294
Market incentives	0.265**			0.160
Self-regulation	0.0860			-0.0268
L.TotInno				0.0226***
Existing × Self		-0.251		-0.197
Future × Self		0.443*		0.264
Financial × Self		0.0745		0.0822
Market × Self		0.173		0.0108
L.TotInno				0.0241***
Path dependency			1.984***	1.900***
Cost savings[Low]			0.240	0.226
Cost savings[Medium]			0.246*	0.209
Cost savings[High]			0.258*	0.179
L.R&D	9.465***	9.802***	6.169***	N/A
EMS	0.223*	0.312***	0.227*	N/A
Size	0.311***	0.317***	0.230***	N/A
Region	0.0151	-0.00487	-0.138	N/A
Sector	Dummy	Dummy	Dummy	N/A
N	1605	1605	1448	N/A

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

of eco-innovation, the estimation results show that the interactions between fulfilment of legal requirements (legally binding instruments), public funding (financial incentives) and market incentives (demand for green innovation), on the one hand, and self-regulation (voluntary commitment), on the other hand, are statistically insignificant suggesting no association with innovation. The only interaction that is positive and statistically significant is between the expectation towards future requirements (future regulation) and self-commitment (self-regulation) supporting the idea

Table 4: Incidence Rate Ratios

	Neoclassical	Evolutionary	Induced innovation	Dynamic
Future-reg	1.317**			1.308**
Market incentives	1.304**			
Future × Self		1.558*		
Path dependency			6.617***	6.038***
Cost savings[Medium]			1.278*	
Cost savings[High]			1.293*	
EMS	1.249*	1.366***	1.255*	N/A
N	1605	1605	1448	N/A

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

of combining the stick and the carrot (Del Río et al., 2010). In terms of interpretations, the IRRs of the statistically significant coefficients reported in table (4) are used. The combination of expectation towards future environmental regulation and self-regulation as an initiating factor for eco-innovation is expected to have an incidence rate for the total number of innovation projects of 1.558 (an increase of 58.8%) for businesses recognizing these factors as relevant for their decision to innovate compared to businesses that considered these factors as irrelevant in their decision to eco-innovate, all other things being equal.

Based on the induced innovation approach of the determinants of eco-innovation, the estimation results show that eco-innovation is indeed path dependent and based on internal factors rather than external factors alone. In fact, all the coefficients are statistically significant, with the exception of businesses that considered the relevance of cost savings as an innovation goal to be low. In terms of interpretations, while holding the other variables constant in the model, businesses that had at least one innovation project in the previous period are six times more likely to innovate in the next period compared to businesses that did not engage in an innovative activity during the previous period. Similarly, businesses considering cost savings as a an innovation goal are expected to have more innovation projects (27.8% for medium and 29.3% for high) compared to businesses considering the goal of cost savings as low or irrelevant in their decision to innovate, all other things being equal. It is also relevant to mention that businesses that account for their environmental impact, through Environment Management Systems for instance, are more likely to innovate, regardless of the theoretical approach.

Finally, when allowing for dynamics the results do not change substantially. In fact, expectations towards future regulation remains positive and statistically significant for the neoclassical approach, while market incentives lose their significant. In the evolutionary approach, the combination of expectations towards future regulation and self-commitment is no longer significant at 5% but remains positive. Finally, in the induced innovation approach, path dependency is just as relevant while cost savings are no longer significant at 5% while remaining positive.

6. Discussion

The empirical results agree with the hypotheses formulated and the findings of previous research. Furthermore, they allow to shed some light on an important question. If environmental regulation is indeed necessary in order to trigger environmental innovation, how should it be designed?

6.1. Neoclassical approach

To answer this central question based on the neoclassical approach, we compare different policy alternatives, namely legally binding instruments, financial and market incentives and self-regulation.

6.1.1. Legally binding instruments

When studying the first alternative, two initiating factors were analysed: the fulfilment of existing legal standards and the expectation towards future legal requirements. Both theoretical and empirical evidence point to the relative ineffectiveness of existing regulation obligation compared to long term performance-based regulation when the aim is to foster environmental innovation, dynamically. As a matter of fact, the former option limits the choice of businesses in term of the technology used to meet the regulatory requirements. On the other hand, performance-based regulation gives businesses the freedom to choose the best technology, and at the same time encourages them to find new, more efficient and effective techniques to meet the long-term regulatory objectives. Besides, when standards are based on a specific technology, they not only encourage end-of-pipe solutions, but may also discourage innovative behaviour due to the regulatory uncertainty inherent to such regulation. That is to say, businesses may refrain from innovating in apprehension of a rise of the regulatory standard. In contrast, performance-based regulation set long-term objectives that are systematically reviewed over a known time-horizon, thus it creates a market for environmental innovation and encourages businesses to find better ways to meet the regulatory objective. Nevertheless, for elected policy-makers, the choice of standard-based environmental regulation over performance-based regulation is motivated by two arguments. The outcome of the latter is less certain and requires longer periods than the former, in addition to difficulty of setting the long-term objectives with the right balance between environmental protection and economic growth. In fact, the objectives should be both ambitious and realistic, otherwise they will either fall short of environmental protection, or will hamper economic growth. An other argument in favour of legally binding instruments is intrinsically linked to the nature of environmental innovation with a distinction between end-of-pipe innovation and other forms of innovation. In fact, the use of end-of-pipe solution might be necessary awaiting a more radical solution.

6.1.2. Incentives

The second policy alternative is financial and market incentives. When studying this alternative, two initiating factors were analysed: public funding and demand for green products. The theoretical arguments could not provide a clear-cut on the effectiveness of financial incentives to foster environmental innovation. Neither did the empirical results. In fact, we show that these instruments are positively associated with environmental innovation only when they are forward looking such as the expectation towards a market demand for green innovation. That being said, it is important to distinguish between price and quantity-based instruments on the one hand, and information-based instruments on the other hand. Although it is necessary to correct market failures inherent to eco-innovation, such as the spillover effect, the former alternative may delay eco-innovation if the design of a subsidy is flawed, due to regulatory capture where special interests affect regulatory intervention in setting R&D subsidies for instance(Dal Bó, 2006). In that case, subsidies may even lead to a perverse effect where businesses rely on end-of-pipe solutions, only to avoid any compliance penalties, because of the lack of an incentive and reward system for innovation beyond compliance. In comparison, information-based instruments rely on improving information flows in order to harness market forces with the aim of fostering eco-innovation. In fact, by educating both the consumer and the producer, policy-makers will create an environment where there is a demand, and thus a market, not only for green products but also for green innovations. These forces can then act freely under the market conditions where the choice of the best technology will be decided based on its effectiveness and efficiency. The diffusion of such technologies will in turn improve its economic performances, thanks to scale, scope and learning effects. At the same time, the demand for green products will create a sound competitive environment for innovators racing to find the next standard-setting technology. Nonetheless, the limits of such policy is the uncertainty around the outcome and the time necessary to reach the intended results. It is also important to note that environmental and technology policy are more effective when the regulator should enable ecological modernization rather than controlling the process of transition.

6.1.3. Self-regulation

Lastly, a third alternative is tested using self-commitment as an initiating factor for environmental innovation. As expected, the empirical results confirmed the theoretical arguments. Clearly, if left unregulated, businesses would not choose to eco-innovate. The decision is based on solid motives which are, unfortunately, not socially optimal. To put it differently, with no regulatory constraints, businesses would not have to internalise the cost of their negative externalities when harming the environment. Additionally, in the event that they decide to eco-innovate, businesses will refrain from doing so continuously for the simple reason that while the whole society benefits from eco-innovation, the sole bearer of the cost is the innovator, not to mention the fact that the technology can then be copied, thus stripping it of its competitive advantage. Finally, the reason no, or little, eco-innovation should be expected without stringent environmental regulation is, partly, because other investment alternatives are, usually, more financially rewarding. In that respect, policy-makers should act to improve the financial attractiveness of investments in environmentally friendly technologies. Therefore, regulatory intervention is, indeed, the *sine qua non* of environmental innovation.

6.2. Evolutionary approach

When exploring the evolutionary, we first came to the conclusion that self-regulation can indeed be effective if, and only if, coupled with the expectation of stringent future regulation and collective liability in case failure in meeting the objectives agreed upon. This situation has been illustrated in different cases such as the Dutch energy benchmarking program or the discussion between the

European Commission and the Auto industry in Europe. Del Río et al. (2010) refers to this approach as "combining the carrot and the stick".

6.3. Induced innovation approach

Lastly, exploring the induced innovation approach allowed us to acknowledge that while innovation is path dependent, the decision to eco-innovate can be stimulated by internal factors, such as cost savings, rather that external factors only. In that sense, national innovation systems need to be adapted in order to break path dependency on old, polluting technologies and stimulate technological change by enabling it rather than controlling all its aspects. To do so, a clear long term vision need to be shared by the stakeholders (economic, public and civil). However, these objectives need to be updated dynamically and systematically, otherwise too much certainty might inhibit eco-innovation.

Conclusion

The objective of this paper is to answer the following research question: which policy is more inclined to foster eco-innovation? To do so, we base our analysis on three theoretical approaches: neoclassical, evolutionary and induced innovation. However, the research on the relationship between policy and the diffusion of innovations is not limited to these three approaches. In fact, some researchers have based their studies on the actor-networks theory (Braun, 2008; Truffer & Coenen, 2012), the systemic approach (Edquist, 1999) or the practice-based approach (Mele & Russo-Spena, 2015). These approaches explore different aspects of eco-innovation such as the role of the position in the network, the role of national innovation systems and institutional factors as well as the non-linear and dynamic nature of innovation. These limitations should be addressed in further research. Similarly, notwithstanding the fact that we control for the sector and the size of businesses, an investigation comparing different sectors or business sizes should allow to draw more practical policy recommendations. By contrast, combining data on different countries over a longer time frame should allow to draw conclusions with more perspective. Nonetheless, the results of this paper allow us to draw the following policy recommendations: conventional regulatory tools, namely legally binding instruments are not effective for triggering innovative behaviour at the firm level while market incentives have a positive effect on the diffusion of innovations. Moreover, there is a market inertia justifying regulatory intervention in order to break path dependency with innovative policy instruments that create a sound and dynamic environment for eco-innovation. In fact, environmental policy should not be "slow, cumbersome, expensive, uncoordinated and uncertain" (Palmer et al., 1992, p. 259), but rather be "proactive, ambitious, open, flexible and knowledge oriented" (Del Río et al., 2010, p. 547) arising from dialogue and consensus. Similarly, the objective of the interaction of technology policy and environmental policy is by no mean to penalize polluting businesses but rather to lift the barriers to eco-innovation allowing the passage to a more sustainable economy (Del Río et al., 2010), what Huber (2000) qualifies of "ecological modernization".

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