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

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Abstract

This article analyses the relationship between environmental regulation and environmental innovation based on the diffusion of innovations theory. The relationship between environmental regulation and environmental innovation is tested using a German firm-based panel and a Dynamic Count Data model. We estimate the propensity of firms to innovate in response to five initiating factors, namely the fulfilment of legal requirements, expectations towards legal requirements, public funding, demand for environmental innovations and self-commitment. We also control for R&D intensity, the region and 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. We show that only dynamic and market-based policies are positively associated with environmental innovation. Conventional regulatory tools, namely technology-based command and control, are not effective for triggering innovative behaviour at the firm level. Lastly, we show that environmental regulation is a necessary condition for eco-innovation.
Keywords: Porter Hypothesis, Environmental regulation, Environmental innovation, Diffusion of innovations, Dynamic 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 and the process of adoption of innovations. The applications of this theory went beyond its original domain. In fact, in this paper we use the methodology proposed by the diffusion of innovations theory and apply it to environmental innovation. In 1991, Michael E. Porter published a short, yet controversial, article where he explains that stricter environmental regulation could, in reality, improve business competitiveness through environmental innovation. This claim will later be known as the Porter hypothesis. It goes without saying that such a claim from a renowned 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, we limit the investigation to the relationship between environmental regulation and environmental innovation, also known as the weak Porter hypothesis. 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. The objective is to answer the following question: which policy is more inclined to foster innovative behaviour at the firm level? In order

[☆] Panel data collected by the German Center for European Economic Research in Mannheim (ZEW) as part of the European Community Innovation Survey.

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to answer this question three alternatives are compared: command and control regulation, market-based regulation and no regulatory intervention. 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). As a matter of fact, the lack of dynamics is one of the recurrent shortcomings in testing the Porter hypothesis as noted by Jaffe & Palmer (1997) and more recently by Lanoie et al. (2008). Accordingly, a Dynamic Count Data model is used to estimate the propensity of firms to innovate in response to a set of five initiating factors, namely the fulfilment of legal requirements, expectations towards legal requirements, public funding, demand for environmental innovations and self-commitment. We suspect the fulfilment of legal requirements to be ineffective in fostering innovation since there is no incentive to further innovate once the standard set by the regulator is met. By contrast, we suspect a positive association with the expectation towards future legal requirements since the effect is dynamic with an incentive for the first-mover. Similarly, we expect to see a positive association between the total number of innovation projects and public funding as well as the demand for green products. However, we believe that the self-commitment will not be positively correlated with innovation. In addition, we control for research and development intensity (Griliches, 1979) (as cited in McWilliams & Siegel (2000)) and the size of the company. This factor is suspected to be responsible for an important omitted-variable bias causing model misspecification. We also control for the region (eastern/western Germany) and potential industry bias by restricting the data using 23 sectoral dummies (Wagner, 2010; Busch & Hoffmann, 2011), and filter for companies that account for their environmental impact. The results obtained allow us to draw the following conclusions: conventional regulatory tools, namely standards-based policies are not effective for triggering innovative behaviour at the firm level; market-based policies have a positive effect on the diffusion of innovation; there is a market inertia justifying regulatory intervention.
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

Stoneman & Battisti (2010) define the diffusion of new technology 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, with no spatial boundaries. According to the authors, the concept of newness is relative as well. They distinguish two levels: the world and the firm, thus allowing for a differentiation between global and local innovation. Concerning the levels of the diffusion Stoneman & Battisti (2010) list four levels depending on the aggregation: international (imported new technology), national (at the industry level), inter-firm (within industry) and intra-firm/household. Government intervention in the process of the diffusion of new technology is justified by the existence of a market failure due to the spillover effect. Indeed, because of technological externalities, the innovator will not be able to appropriate all the benefits and costs of the new technology (Stoneman & Battisti, 2010). In their article, Murphy & Gouldson (2000) clearly state that with increased awareness of ecological risks, regulators have responded with a program of regulatory reforms arguing that an ecological modernization can result in both economic and environmental benefits. The authors comment on that claim by pointing out that existing work has yet to show the potential of policies to foster ecological innovation. Murphy & Gouldson (2000) add 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 and learning effects result in improved quality and reduced costs over time (Murphy & Gouldson, 2000). Thus, the economic effectiveness of a new innovation is positively associated with its diffusion. When it comes to the implementation of environmental regulation, Murphy & Gouldson (2000) noticed that business would typically choose end-of-pipe solutions to meet regulatory standards such as emission standards with hardly any innovation at all. However, they would resort to abatement technologies (process innovation) in order to meet long-term environmental objectives. For the former solution, the argument is the relative lower costs and the ease of implementation to the existing facilities with no expects of economic benefits aside from avoiding any fines after environmental inspections. For the latter solution, the argument is a strategic orientation with a pro-active move toward increasingly string environmental regulation and social concerns, in addition to tangible benefits in the form of cost reductions, productivity improvements and customer satisfaction. However, this option entails higher costs and lower flexibility since it requires more time to implement. Similarly, Fisher & Freudenburg (2001) describe ecological modernization as being twofold. Indeed, it has to be both economically and politically feasible. In other words, businesses have to take part in the process of ecological change while politics have to ensure environmental protection. In order to meet both expectations, new forms of political interventions are to be used. In his article, Huber (2008) explains that environmental regulation is a necessary condition for eco-innovation. The author states that ”[i]t is stringent regulatory innovation which paves the way for technological environmental innovations” (Huber, 2008, p. 362). On the other hand, the type of regulation used is critical. In effect, if the objective is to foster innovation, then performance standards are to be preferred to best-available-technology standards. Similarly, Johnstone (2005) argues in favour of performance-based measures rather than standards-based type of regulation. The author stresses the absence of incentive to go beyond the standard with standards-based regulation while the performance-based 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.

3. Hypotheses development

Based on the literature review, five hypotheses are formulated to be later tested by the model empirically.

Hypothesis 1 *Standards-based regulation does not foster innovation*

Evidence from the literature show that standards-based regulation, or command and control 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 being realistically feasible by businesses. The balance between these two objectives is no easy task. Another limit is the fact that however ambitious a standard is, once it is met by businesses there is no incentive to go beyond the regulatory requirement, thus limiting the prospect of future technological 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. However, this solution limits the technological choices to achieve the regulatory objective, and therefore removes the incentive to develop new ways to reduce environmental harm (Jaffe & Stavins, 1995). Moreover, Jaffe & Stavins (1995) warn against a counter-effect of such regulation. The authors argue that innovative businesses may fear to develop new technologies in order to avoid a likely rise of the regulatory standards.
The theoretical arguments are, explicitly, pointing out the ineffectiveness of standards-based regulation to foster innovation, hence our hypothesis.

Hypothesis 2 *Performance-based regulation does foster innovation*

In contrast with standard-based 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 without specifying the 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 business (Zarker & Kerr, 2008). Also,

the 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.
Therefore, the theoretical arguments seem to agree with the hypothesis that performance-based regulation does foster innovation.

Hypothesis 3 *Financial policy instruments foster innovation*

Contrary to command and control regulation, which is considered direct regulation, financial policy instruments 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 instruments are limited to the different forms of taxes and 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 tax for instance, the value should reflect the cost of the environmental harm, while in the case of subsidy, the value should reflect the positive spillover of eco-innovation. 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. However, Andersen & Sprenger (2000) warn against the perverse effect of such instruments. In the case of subsidies, for instance, Andersen & Sprenger (2000) noted that the lack of an incentive and reward system led them to reduced levels of investment in pollution reduction technologies and favoured end-of-pipe solutions.
The theoretical arguments do not seem to provide a clear-cut to whether such instruments foster or hinder innovation. Nonetheless, we hypothesize that financial policy instrument do foster innovation.

Hypothesis 4 *Market-based incentives do 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 1.
Rennings (2000) refers to these market forces 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, cleaner product this will create a market for eco-innovations, and thus foster 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) provide a comprehensive list of such instruments. They list 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 comment 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 to go well beyond compliance.

Hypothesis 5 *Regulatory intervention is necessary to foster innovation*

Many researchers have observed that unregulated businesses would rarely choose 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 public

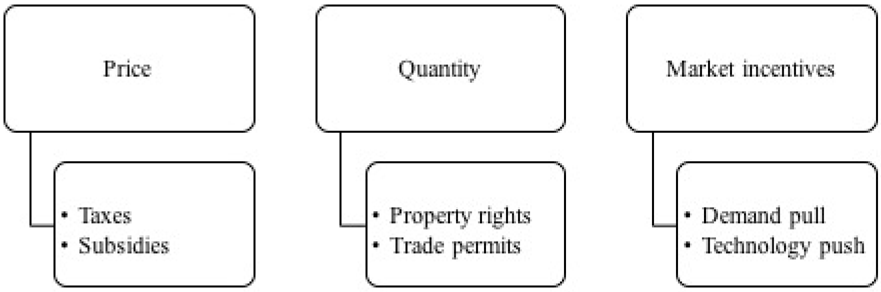

Figure 1: Typology of market-based policy instruments
Source: Adapted from Whitten et al. (2003)

good. 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 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.

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 claim 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 to seize such business opportunities (Ambec & Barla, 2006). However, Ambec & Lanoie (2008) commented on those results by pointing out that the methodologies used have been lacking dynamics. 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 process requires time, while 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 continue to argue that when Lanoie et al. (2008) allowed for a lag in time, they found that stringent regulation had a greater impact on productivity gains. Following those arguments, the model that has been chosen to test the relationship between environmental regulation and the diffusion of innovations is a Dynamic Count Panel Data Model. 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 those conditions, Cameron & Trivedi (2013) explain that the negative binomial model is necessary if the count variable is incomplete due to truncation for instance, which is the case of the total number of innovation projects. In order to allow for dependence over time, the lagged values of the dependent variable are included to the model as a regressor.

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

$$y_{it} = \rho y_{it-1} + x_{it}^{'}\beta + w_i^{'}\gamma + \nu_i \tag{1}$$

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

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 of the paper 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. The following simplified empirical model is specified:

$$TotInno = f(IFs, R\&D, EMS, Size, Region, Sector) + \epsilon \tag{3}$$

Where:
$TotInno$ is the dependent variable measuring the total number of innovation projects.
IFs are the five initiating factors of environmental innovation.
$R\&D$ is the innovation intensity of the company.
EMS is a dummy variable that filters companies that account for their environmental impact.
$Size$ is a categorical variable that classifies companies according to the number of their full-time employees.
$Region$ is a dummy variable controlling for the region of the company (Eastern/western Germany).
$Sector$ is a dummy variable accounting for the sector of the company.

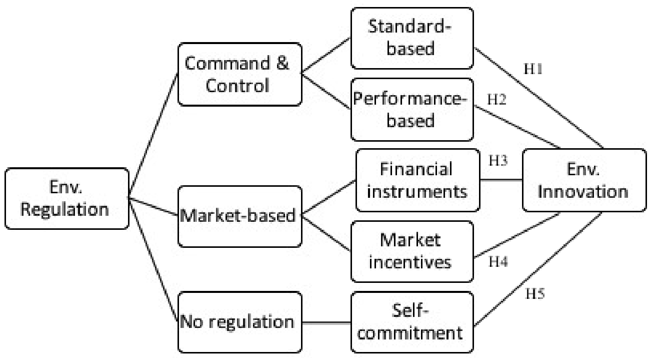

Figure 2: Theoretical model

The theoretical model tested is represented in figure 2. Environmental regulation is linked to environmental innovation through the different policy alternative. The effectiveness of each policy option in fostering innovation is tested empirically. Practically, three alternatives are compared: command and control regulation, market-based regulation and no regulatory intervention. A distinction between standard-based and performance-based regulation is made. Both are considered 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. A simple example would be CO_2 emissions. 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. Concerning market based regulation, a distinction between financial instruments and market incentives is made. In the case of CCS, the former option would take the form of a Pigovian tax imposed on CO_2 emissions and/or tax credits for avoided emission as a financial incentive (Nordhaus, 2011). Alternatively, the regulator could set up a cap and trade system with an allocation (or auctioning) of carbon emissions allowances, thus creating a market for CO_2 emissions. Both market based instruments are expected to be more effective than command and control regulation 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, the number of participants is too few to 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 (Zentrum für Europäische Wirtschaftsforschung). 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 closure 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 examples, 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. As a matter of fact, those conditions are particularity adapted to test the hypotheses formulated in section 3.

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 model tested in this paper. In order to allow for dynamics, three data sets were merged since the data are collected on a yearly basis and come in separate sets. The dependent variable used is the total number of innovation projects. To collect the data on this variable, business had to answer the following question: What was the total number of innovation projects (including R&D projects) carried out in your enterprise during 2009-2011? (newly started, ended, 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

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)

particular interest in order to study the innovative behaviour of businesses in response to a set of policies, dynamically.

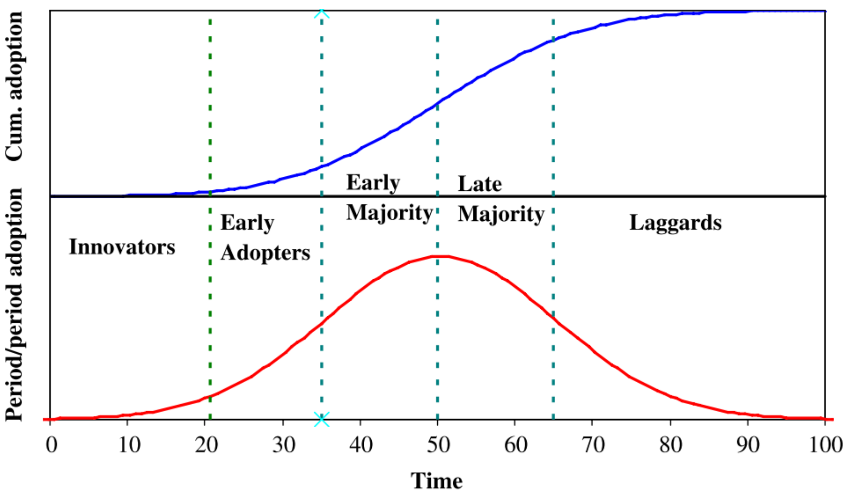

Figure 3: Diffusion of innovation
Source: Meade & Islam (2006)

Table 2: Descriptive statistics of the estimation sample

Variable	Mean	Std. Dev.	Min.	Max.
TotInno	5.452	44.039	0	1500
Standard-based	0.182	0.386	0	1
Performance-based	0.168	0.374	0	1
Financial instruments	0.059	0.236	0	1
Market incentives	0.161	0.368	0	1
No regulation	0.171	0.377	0	1
R&D	0.016	0.041	0	0.25
EMS	0.14	0.347	0	1
Region	0.327	0.469	0	1
Size	1.513	0.699	1	3
Sector	12.403	6.548	1	23

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 five environmental innovation initiating factors, namely the fulfilment of legal requirements, expectations towards legal requirements, public funding, demand for environmental innovations and self-commitment. To collect the data on those variables businesses had to answer the following question: During 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.

In addition, a filter is applied to identify environmentally friendly businesses that have set-up an environmental management system. The corresponding question is the following: 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,...). Finally, we controlled for research and development intensity (Griliches, 1979) (as cited in 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 controlled for the region (eastern/western Germany) and the potential industry bias by restricting the data using 23 sectoral dummies (Wagner (2010); Busch & Hoffmann (2011)). The estimation results are shown in section 5 below.

5. Results

The results of the model 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 1431 companies, in 23 different sectors over a period of 5 years (2006-2011). The estimation results are summarised in table 3. Firstly, the coefficient of the fulfilment of legal requirements (standard-based regulation) was statistically insignificant suggesting no association with innovation. Secondly, the coefficient of the expectation towards future requirements (performance-based regulation) was as expected positive and

Table 3: Estimation results

	Coefficient	IRR
TotInno		
L.TotInno	0.00152***	
	(3.51)	
Standard-based	0.0186	1.0187
	(0.16)	
Performance-based	0.483***	1.6217
	(3.88)	
Financial instruments	0.421*	1.524
	(2.30)	
Market incentives	0.362**	1.4359
	(3.09)	
No regulation	-0.149	0.8619
	(-1.16)	
R&D	5.759***	
	(6.35)	
EMS	0.182	
	(1.48)	
Region	0.0687	
	(0.75)	
Size :		
50-249	0.509***	
	(5.16)	
$\geq$ 250	1.057***	
	(7.55)	
Sector	Dummy	
_cons	-1.684***	
	(-5.13)	
ln_r		
_cons	0.594***	
	(8.09)	
ln_s		
_cons	0.858***	
	(6.38)	
N	1431	

t statistics in parentheses

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

statistically significant. Thirdly, the coefficient of the public funding (financial instruments) was positive and statistically significant. Fourthly, the coefficient of the demand for green products (market incentives) was as expected positive and statistically significant. Lastly, self-commitment (no regulation) was not correlated with innovation.

In terms of interpretations, the Incidence Rate Ratios (IRRs) 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, only three have statistically significant coefficients: performance-based, financial instruments and market incentives. The first IIR represents the estimated rate ratio 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 variable constant in the model, performance-based regulation is expected to have an incidence rate for the total number of innovation projects of 1.6217 (an increase of 62.17%). Similarly, financial instruments and market incentives are expected to have an estimated incidence rate for the total number of innovation projects of 1.524 and 1.4359 (an increase of 52.4% and 43.59%), respectively, for businesses recognizing these factors as relevant for their decision to innovate, all other things being equal.

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? To answer this central question, we compare different policy alternatives, namely command and control regulation, market-based regulation and no regulatory intervention. When studying the first alternative, two initiating factors were used: the fulfilment of existing legal standards and the expectation towards future legal requirements. Both theoretical and empirical evidence point out that standard-based regulation is less effective than performance-based regulation if the aim is to foster environmental innovation. 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 set long-term objectives that are systematically reviewed over a known time-horizon creating a market for environmental innovation and encouraging 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, otherwise they will fall short of environmental protection, while remaining realistically feasible, otherwise they will hamper the economic growth.

The second policy alternative is market-based regulation. When studying this alternative, two initiating factors were used: public funding and demand for green products. The theoretical arguments could not provide a clear-cut on the effectiveness of financial market-based policy instruments to foster environmental innovation. However, the empirical results show that these instruments are indeed positively associated with environmental 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 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 the tax or subsidy is flawed, due to regulatory capture for instance, or 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 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.

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 for 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 the *sine qua non* of environmental innovation.

To conclude, the results allow us to draw the following analysis: conventional regulatory tools, namely command and control are not effective for triggering innovative behaviour at the firm level while market-based mechanisms have a positive effect on the diffusion of innovations. Moreover, there is a market inertia justifying regulatory intervention with innovative policy instruments that create a sound and dynamic environment for eco-innovation.

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