Discussion Paper No. 10-074

Long-Term Impacts of Environmental Policy and Eco-Innovative Activities of Firms

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Non-Technical Summary

This paper investigates two central questions. Are there long-term effects of regulation on innovation? Does the impact of different types of regulation differ by type of the environmental benefit of the innovations? The overwhelming majority of regulations considered in this paper are of the command-and-control type, and thus, non-market based. The theoretical literature offers clear arguments, why command-and-control regulations are not dynamically efficient, which means that they do not provide a sufficient amount of long-term innovative incentives compared to market based instruments. One possible explanation might be that there is no further need to adapt after a given performance standard is achieved. Nevertheless, a notable amount of firms stated in the European Community Innovation Survey (CIS) that environmentally related innovations have been introduced in response to regulations from the 1950s and 1970s. Therefore, contrary to conventional wisdom, non-market based regulation might also provide a certain amount of long-term innovative incentives.

The present study uses data from the German part of the CIS in 2009, the Mannheim Innovation Panel (MIP). Evidence for nine different classes of environmental benefits of introduced innovations is provided by a question where firms were asked to state the amount of environmental benefits (ranging between no, low, medium, and high benefits). Furthermore, firms were asked about the determinants of these innovations. The focus in this paper is only on governmental regulation. In cases where innovations are introduced due to regulatory constraints, firms were asked to cite the respective laws to be responsible for these innovations. These laws were classified into three major fields of environmental policy and furthermore, the effective dates of these laws were identified. Almost all of the cited regulations are non-market based.

The ordered probit estimation approach used in this paper provides only limited support for innovative effects of these three policy types in general. They only trigger environmentally related innovations for strongly related environmental aspects. In addition to this finding, the results provide evidence for long-term innovative effects of command-and-control regulation. However, such long-term effects of regulation on environmentally related innovation do not exist for all of the examined environmental benefits of innovations.

Das Wichtigste in Kürze

In diesem Aufsatz werden zwei zentrale Fragestellungen untersucht. Zum einen, ob es Langzeiteffekte von Umweltregulierungen auf Innovationsaktivitäten mit Umweltrelevanz von Unternehmen gibt. Zum anderen wird danach gefragt, inwieweit sich verschiedene Typen von Umweltpolitikmaßnahmen in ihrer Wirkung auf Innovationen mit verschiedenen Umweltwirkungen unterscheiden. Die überwiegende Mehrheit der hier untersuchten Regulierungen entstammt dem Ordnungsrecht, ist also nicht marktbasiert. In der theoretischen Literatur ist relativ unstrittig, dass ordnungsrechtliche Politikmaßnahmen nicht dynamisch effizient sind, d.h. dass von ihnen keine hinreichend hohen bzw. kaum dauerhafte Innovationsanreize ausgehen verglichen mit marktbasierten Instrumenten. Ein Grund hierfür mag sein, dass kein weiterer Anpassungsbedarf an gesetzliche Vorschriften mehr besteht sofern ein gewisser Umweltstandard erreicht worden ist. Dennoch gab eine beträchtliche Anzahl von Unternehmen in der europaweiten Innovationserhebung (CIS) an, dass sie aufgrund staatlicher Regulierungen aus den 1950er und 1970er Jahren Innovationen mit Umweltrelevanz eingeführt haben. Aus diesem Grund ist zu erwarten, dass – entgegen der vorherrschenden Meinung – auch von nicht marktbasierten Instrumenten der Umweltpolitik durchaus langfristige Innovationsanreize ausgehen können.

Diese Studie verwendet Daten aus der deutschen Erhebung des CIS von 2009, dem Mannheimer Innovationspanel (MIP). Aufschluss über die eingeführten Innovationen mit Umweltrelevanz in insgesamt neun verschiedenen Kategorien gibt eine Frage, bei der die Firmen zwischen keinem, wenig, mittlerem und hohem Beitrag zum Umweltschutz der eingeführten Innovationen wählen können. Zusätzlich wurden die Untenehmen nach den Treibern genau dieser Innovationen befragt, von denen wir uns ausschließlich auf staatliche Regulierung konzentrieren. Wurden Innovationen aufgrund von Regulierungen eingeführt, so wurde zusätzlich nach den konkreten Gesetzen und Vorschriften gefragt. Diese Gesetze wurden in drei zentrale Umweltpolitikfelder eingeordnet und für jede genannte Regulierung deren Zeitpunkt des Inkrafttretens ermittelt. Es wurden überwiegend ordnungsrechtliche Vorschriften zitiert.

Die in diesem Aufsatz verwendete Ordered Probit Schätzung zeigt, dass von diesen drei Typen von Umweltpolitikmaßnahmen nur beschränkte Innovationswirkungen auf unmittelbar regulierte Umweltprobleme ausgehen. Es zeigt sich jedoch auch, dass von ordnungsrechtlichen Maßnahmen durchaus langfristige Innovationswirkungen ausgehen können, allerdings nicht für alle der hier untersuchten Bereiche des Umweltschutzes.

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Abstract: This paper analyses two aspects of environmental regulations triggered by eco-innovations. First, whether there are long term effects of regulation on innovation. Second, whether the impact of different types of regulation differ by type of the environmental benefit of the innovations. To answer these questions, the paper uses firm level data from the German part of the Community Innovation Survey 2009, in which companies were asked to cite the respective regulations to be responsive for the firms' introduced environmental related innovations. Regulations quoted by firms are classified into several policy types and also the age the respective regulations are calculated. We find evidence for long-term effects of environmental regulation on innovation. Furthermore, different types of regulations varied with respect to their impact on several environmental benefits of innovations.

Keywords: Environmental policy, environmental innovation, innovation surveys

JEL classification: Q55, Q58, Q01, C83

1 Introduction

In the last decades, environmental concerns were increasingly considered by policymakers. However, in order not to hamper national competitiveness and economic growth, environmentally friendly technological changes are necessary to ensure mitigation of environmental burdens. The present paper will not discuss the determinants of these environmentally related technological changes. It will instead focus on one special driver of environmental innovations: governmental regulations. Regarding this special driver of environmental regulation, there has been a lively debate especially regarding the costs and benefits of regulation and innovation (see Porter and van der Linde 1995; Palmer et al. 1995). The present paper does not participate in this debate. It tries to answer two central research questions: First, whether there are long term effects of environmental regulations on innovations. Second, whether the impact of different types of environmental policy differs by type of eco-innovative activities of firms.

For this purpose we use firm level data on innovative activities with environmental impacts from the German part of the Community Innovation Panel (CIS) 2009. The database provides information about special regulations which forced firms to introduce innovations with positive environmental impact in nine different categories. For regulations to be responsive for firms environmental innovations, we calculate the age of the cited regulations in order to shed light on the question whether there are long-term effects of old regulations on innovations.

Regulations in our database are mostly of the command-and-control type. These regulations have some important disadvantages in so far as they do not enable equalization of marginal pollution abatement costs and dynamic efficiency. Thus, the conventional wisdom would be that there are no long-term effects of command-and-control regulations. This is indeed anticipated, because companies have no incentive to innovate further after a required environmental standard is achieved. However, this paper identifies long-term effects of regulation on the majority of the different environmental impacts of innovations.

In addition to this, the second research question deals with the impact of different types of command-and-control regulation with regard to different environmental impacts of innovations. This research question needs to classify regulations quoted by companies according to major policy types. Also for this research question the paper finds evidence. The main result is that types of regulations differ with respect to their impact on several environmental benefits of innovations. However, the results are weak with respect to some of the examined environmental benefits.

To our knowledge, both, to use the age of environmental regulations and their classification with regard to several policy types are novel in such an analysis. Especially the first research question regarding the long-term effects of regulation on innovation is a new way of analysing this topic.

The rest of the paper is organized as follows. The following section presents important research on the impact of environmental regulation on innovation. Section three gives a brief discussion of Germany's environmental regulation development. This is required in order to define the policy phases for the econometric analysis presented in section four. The results are given in section five, followed by a brief discussion of the results and suggestions for further research in section six. Section seven concludes.

2 Environmental innovation and regulation

Before dealing with the term "eco-innovation", it is necessary to define what is covered by the term in the present paper, because the definition used here differs in some ways from what an economist normally would call an innovation. Normally, innovation is defined to be the first introduction of a new product, process, service or organizational structure into the market (Schumpeter, 1934). In this analysis, however, innovations with positive environmental impacts (hereafter eco-innovations) are defined to be environmental related innovations per se and also the adoption of these innovations. Why? The CIS data used in this paper can hardly distinguish between the first introduction on the market or the novelty only to the firm. The simple reason is that to a considerable degree, even companies do not know whether a new process or product, leading to less environmental burdens, is new to the market or only new to them. To put it in a nutshell: the definition used in this essay does not distinguish between innovation and technology diffusion or adoption. Kemp and Pearson (2008) use a similar definition.

Apart from other factors such as market forces, environmental policy has been identified as an important driving force for innovations with environmental benefits; see Jaffe et al. (2002) for a comprehensive literature survey. Based on some case studies, Porter (1991) and Porter and van der Linde (1995) find that innovations are introduced in response to environmental regulation. They also argue that these innovations increase competitiveness. Lanjouw and Mody (1996) find evidence by looking at patent applications that environmental regulation stimulates related innovations. Newell et al. (1999) find empirical evidence that, beside other impact factors, governmental regulation leads to energy efficiency innovations. The study of Brunnermeier and Cohen (2003) reveals evidence for innovations stimulated by pollution abatement and control expenditure, which is a measure for regulatory burdens. In contrast to these findings, Jaffe and Palmer (1997) find no significant impact of regulatory compliance costs on patent applications by applying a macro-level panel data analysis. Furthermore, a study of Snyder et al. (2003) comes to the conclusion that there is no significant impact of regulation on technology adoption at all.

Also in analysis of innovation surveys regulation has been identified as an important determinant of environmental innovation (together with technology push, market pull and firm-specific factors). In this context, the impact of regulation on innovation is discussed as “regulatory push/pull effect” (Rennings 2000). The regulatory push/pull effect has been confirmed by several survey studies, including Green (1994), Cleff and Rennings (1999), Rennings and Zwick (2002), and Horbach (2008). Del Rio Gonzalez (2005) identified regulation pressure and corporate image as the main incentives for adopting cleaner technology in the Spanish pulp and paper industry. Frondel et al. (2007) find that generally policy stringency is an increasingly important driving force behind environmental innovations rather than the choice of single policy instruments. Arimura et al. (2007) provide the same empirical evidence for the effect of regulation on green R&D, i.e. that stringent environmental policy stimulates green R&D rather than the choice of a certain policy instrument. Facilities facing very stringent environmental regulation are more likely to conduct environmental R&D.

The regulatory push/pull effect has also been confirmed by patent studies. Recently, Popp (2006) found evidence in a study with patent data from the United States, Japan and Germany that innovation decisions of companies were mainly driven by national regulation, not by regulation abroad. Johnstone et al. (2010, p. 146) find evidence for the special case of renewable energy innovation that “[…] policy, rather than prices, appears to be the main driver of innovation in these technologies”.

So far, literature on the relationship between environmental policy and technological change has mainly focused on the choice of an optimal policy instrument to trigger environmental innovations (Jaffe et al., 2002). The superiority of market-based instruments like taxes and tradable permits has long been the basic tenet in environmental economics. These instruments were identified as environmental policy instruments with the highest dynamic efficiency (innovation efficiency). Their advantage is that they provide permanent incentives for further, cost-efficient emissions reductions. Or as Jaffe and Stavins (1995) summarise: “Theoretical economic analysis have generally supported the notion that market based approaches provide the most effective *long-term* incentives for invention, innovation, and diffusion" (Jaffe and Stavins 1995, p. S-45). Furthermore, they provide empirical support for the case of housing efficiency innovations.

Traditionally, command and control regulation is the most popular instrument for avoiding environmental externalities. It is a general term for regulatory requirements, standards or prohibitions. In economic literature most economists consider command-and-control regulation to be less preferable than market-based approaches. Rightly, it is often argued that command and control regulation does not provide efficient incentives for abatement of environmental externalities and because of this, it provides little incentives for environmental innovation. However, as mentioned before in the introduction, we expect innovation effects of command and control instruments to be more dynamic than assumed in theory. Needless to say that in this study, we cannot compare the dynamic effects of command-and-control with those of market-based instruments, since we only have information on non-market based regulations. Such comparison is offered for instance by Downing and White (1986), and Milliman and Prince (1989). As it might be expected, they found direct controls (command-and-control) to perform worst with regard to dynamic innovation effects compared to auctioned permits or emission taxes[1]. Kerr and Newell (2003) provide empirical support based on an analysis of the petroleum industry. They find that lead-reducing technology adoption is higher under market based regulation than under performance standards. Also Porter (1991) and Porter and van der Linde (1995) argue that market-based regulations provide greater incentives for introducing environmental innovations. Nevertheless, this paper tries to shed light on the question whether there are long-term effects of command-and-control regulations on innovative activities.

We think this is also of some interest since command-and-control regulation seems to be favourable under some very limited circumstances. As Hahn and Stavins (1992) argue, such cases are for instance highly localized pollution problems where source-specific standards could be more appropriate. Furthermore, even against the background of the superiority of market-based regulations, command-and-control is the most common policy instrument. Stavins (1998) argues that political economy constraints may account for this situation.

[1] An interesting empirical result is offered by Popp (2003). Surprisingly Popp concludes that innovative activities under command and control regulation are higher than under the permit market. But Popp (2003) also finds that innovation to comply with command and control regulation is only done to lower regulatory compliance costs but not to reduce emissions. However, the market based instrument leads to R&D with regard to both cost savings and reduction of emissions.

Is there any evidence for long-term dynamic effects of command-and-control regulation on environmental innovations? By using US patent data, Popp (2002) found evidence that increasing energy prices result in energy saving innovations at a later stage. More precisely, he argues that for using unweighted counts of patents "half of the effect of the 1973 oil price shock on innovation would have passed by 1987" (Popp 2002, p. 173). For the weighted patent data, the estimated time lag was lower (4.86 years on average). Are these findings of Popp (2002) also relevant for a study on long-term effects of command-and-control regulation on innovation rather than for an effect of price changes on innovation? We think they are. This is because by assuming that tightened environmental regulations increase the "probability of a sanction for violating a performance standard" (Jaffe and Stavins 1995, p. 47), the expected costs for violating these regulations will rise, too. This allows an interpretation of such tightened regulations as increases in relative prices for using the more polluting technology. Jaffe and Stavins (1995) used a similar approach. In their model, the time of technology adoption amongst other things depends on the "probability of a sanction for violating a performance standard" (Jaffe and Stavins 1995, p. 47). To our knowledge, the finding of Popp (2002) that the 1973 oil price shock still triggered innovation until 1987 is the only empirical evidence of such long-term effects[2]. For command-and-control regulation rather than oil price shocks, there is no comparable study. Therefore, the present approach tries to close this research gap.

3 Environmental regulation in Germany

The development of the German environmental policy can be divided into several phases which will be discussed in some detail below. Note that there is no unified classification of the different phases or types in literature. Literature tends to classify environmental policy phases by time or election periods (see i.e. Jänicke et al. 2003 or Schmidt 2007). By defining phases of environmental policy, we deviate from German environmental policy literature and distribute environmental standards, laws, and regulations into four categories: First, the End-of-Pipe category, which includes for example the BImSchG, TA-Luft, REACH and more. Second, we introduce a category which covers the circular economy policy regulations like

[2] Please note that long term effects should not be mistaken for time lags. Without any doubts, innovative activities, regardless of whereof they are triggered, need time until innovation output is created. As mentioned, we are not able to measure innovation per se. Our database measures innovation and adoption together. A time lag is the time span from the impulse to engage in innovative activities until the innovation is introduced into the market. If it is ask for long term effects, however, it is meant whether impulses from years ago (like old regulations) can still today provide incentives to adopt innovations. Since it is unlikely that an innovation activity triggered by the 1973 oil price shock and started at this time needs until 1987 or later to be finished (that would be a large time lag), the findings of Popp (2002) can regarded to be such long term effects.

the VerpackV, KrW-/AbfG, RoHS and WEEE. Third, a category for managerial environmental policies is introduced here, including for instance the EMAS or ISO 14001 guideline. The climate protection policies are summarized into a fourth class, including for instance the EEG, EnEV, EuP and many more.

Sectoral End-of-Pipe

This phase includes the first two periods of environmental policy in Germany. The first can also be called the phase of establishment (1969 up to 1973). This period is characterised by broad governmental initiatives for basic environmental regulations (Jänicke et al., 2003). The most important example of this early green policy is the environmental program of 1971, which allowed environmental policy to be of the same importance as other fields of policy (Wicke, 1993; Altmann, 1997). More than 100 laws were enacted within this period (Jänicke, 2009). It has often been criticised that this early environmental policy only consisted of measures for the redistribution of pollutants rather than a strict pollutant abatement policy (Jänicke et al., 2003). This phase can also be characterised as the "policy of the high chimney". The following, second phase from 1974-1982 is characterised by a slowdown of environmental policy initiatives by the government. Because of recessions after the two oil crises in 1974 and 1980/81, environmental policy received less attention by policymakers and was more than ever discredited to be a job-killer (Schmidt, 2007). Nevertheless, important regulations were created in this phase, like the Federal Immission Control Act (BImschG) in 1974 to limit harmful pollutants, noise, etc. Thus, this phase of German environmental policy is characterised by an ongoing policy of the distribution of pollutants like in the phase from 1969 up to 1973 but also by further end-of-pipe regulations, especially for water pollution control (Jänicke et al, 2003).

As end-of-pipe regulations were also created in later phases (i.e. the "TA Luft" from 1986 or the REACH act from 2007, which encompasses the registration, evaluation, authorisation and restriction of chemicals) and older regulations were revised, we subsume all these emission regulation reforms or tightening under one general policy phase (or policy type) that we call end-of-pipe regulation.

Cleaner production

The next phase is characterised by increasing activities concerning environmental issues by the new government in 1982. In the literature there is no unified opinion on the length of these periods. Schmidt (2007) defines the end of this phase as the beginning of the administration of the social democratic and green (environmental) government in 1998. In contrast, Jänicke et al. (2003) approximately equate the environmental policy phases with the administration periods. In the recent approach, we define this phase of environmental regulation to consist of cleaner production policies like for instance the environment damage act (USchadG). Furthermore, existing end-of-pipe regulations have been improved within this period. In the German Innovation Panel 2009, only a very small number of companies referred to regulations belonging to cleaner production policy. For this reason, we do not introduce a phase of cleaner production on it's own. Other regulations from this phase are also of the end-of-pipe type.

Circular-Flow-Economy

According to Jänicke et al. (2003), we set the beginning of the third phase of environmental standards for the year 1988. A large part of this phase belongs to the age of environmental minister Klaus Töpfer, including several take back systems. Important regulations of this phase are for instance the Packaging Act (VerpackV from 1991) for reducing environmental burdens from packaging waste or the Act for Promoting Closed Substance Cycle Waste Management and Ensuring Environmentally Compatible Waste Disposal (KrW-/AbfG from 1996) which can be seen as the central German law related to waste disposal. There are also newer circular economy regulations like for instance the RoHS and the WEEE guidelines from 2002 by the European Community. The RoHS guideline limits the use of hazardous chemicals in electronic appliances and the goal of the WEEE directive is to reduce electronic waste by a guideline for producers of electronic appliances. With regard to these examples and further laws and acts since 1988 relating to waste disposal and resource recycling, we define this phase as the policy type of circular-flow-economy regulation.

Climate Policy

The begin of the mandate of the "greener" government in 1998, consisting of social democrats and the green party, opened new opportunities for further environmental protection policies (Jänicke, 2009). Within this election period, many regulations for reducing green house gas emissions were passed. The most important regulations are the Renewable Energy Sources Act (EEG) of 2000, the Energy Saving Act (EnEV) of 2002 and the Combined Heat and Power Act (KWKG) of 2002. A further important regulation from this period is the Directive for Energy using Products (EuP) by the European Commission in 2005. Because all these acts and directives were passed for climate change mitigation, we will subsume them under the main category of climate policy.

The figure below presents all three mentioned policy types we defined above in a temporal order.

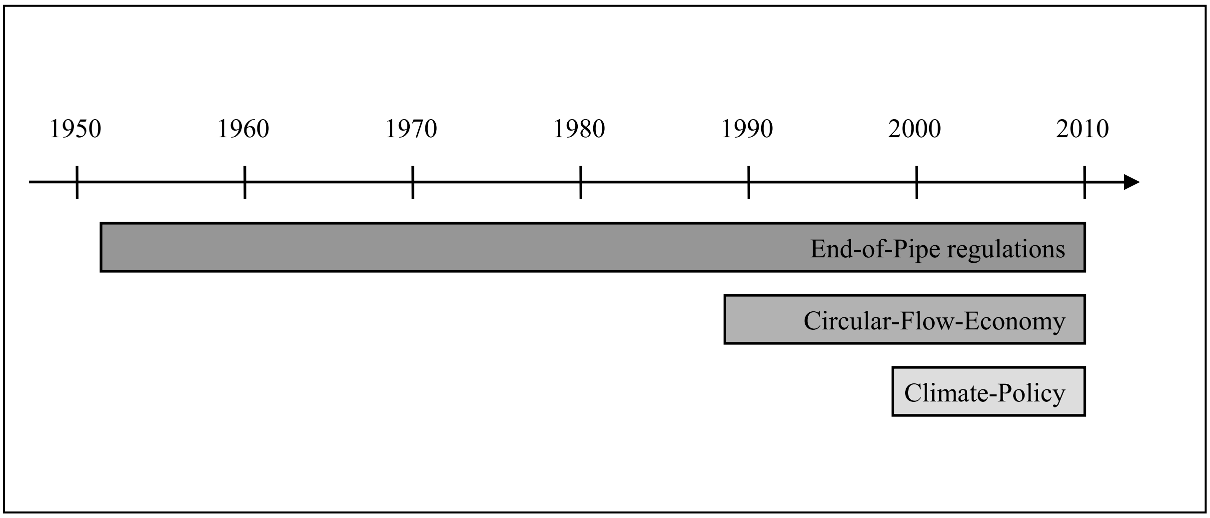

Figure 1: Temporal order of the defined policy phases

4 Database and descriptive statistics

The present paper uses data from the 2009 version of the Mannheim Innovation Panel (MIP) which is the German part of the Community Innovation Survey (CIS). Here, companies were asked whether they introduced innovations with positive environmental benefits, in the following areas: a) a decline of material usage, b) a reduction of energy use, c) a reduction of CO_2 emissions, d) a reduction of air emissions (i.e. SO_x, NO_x), e) a reduction of water pollution, f) a reduction of soil pollution, g) a reduction of noise, h) a compensation for dangerous inputs, or i) an improvement of recycling. These nine questions serve as our dependent variables. Consequently, the model which will be discussed in the next section is calculated for every of the nine different environmental benefits of innovations separately.

The recent approach uses data from 419 observations in which firms stated that these innovations where introduced due to environmental regulation. Even more important, the companies reported the respective regulations to be responsive for innovations. As it was argued in the introduction, we expect regulation to differ in its impact on the nine categories. In another step, the age of the cited regulations was identified and each regulation mentioned by the firms was distributed to the three types of environmental policy already defined in the previous section (end-of-pipe (T_EOP), circular-flow-economy (T_CFE), and climate-policy (T_CPO)). To put it in a nutshell: the recent paper is not interested in the determinants of innovation with environmental benefits. It is rather interested in the impact of different policy types and especially on long term effects of environmental policy on innovation with environmental benefits in the nine categories. In addition to data on environmental innovation and regulation, the MIP offers other corporate data, like the number of employees, industry affiliation, etc. The number of employees serves as a measure for company size in the present approach.

The descriptive statistics for the independent variables used in this paper are presented in the table below.

Table2: Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
T_EOP	419	0.601432	0.4901888	0	1
T_CFE	419	0.2529833	0.4352411	0	1
T_CPO	419	0.2410501	0.428232	0	1
AGE	419	13.22434	14.59443	0	52
SIZE	419	2053.866	17655.28	2	282758
EAST	419	0.3126492	0.4641269	0	1
NACE_2	419	0.4582339	0.4988482	0	1
NACE_3	419	0.1885442	0.3916137	0	1
NACE_4	419	0.1073986	0.3099894	0	1
NACE_5	419	0.0405728	0.1975342	0	1
NACE_6	419	0.0334129	0.179927	0	1
NACE_7	419	0.0692124	0.2541184	0	1
NACE_89	419	0.0214797	0.1451503	0	1

60.1 % of the 419 companies who stated laws and regulation to have triggered innovations were affected by end-of-pipe regulations. Further 25.3 % were affected by circular-flow-economy regulation and 24.1 % by climate policy regulations. It is important to note that the circular-flow-economy type contains among other things the RoHS and the WEEE guidelines of the European Commission, which accounts for more than 70 % of all cited circular-flow-economy regulations. As mentioned before, the RoHS guideline limits the use of hazardous chemicals (i.e. lead) in electronic appliances. This fact taken into account, we expect the circular-flow-economy type to have significant impact especially on innovations with positive impacts on the compensation for dangerous inputs. In addition to this, the WEEE regulation sets standards for the recyclability of electronic products, and is therefore expected to affect innovations with positive impact on improvements of recycling possibilities to a significant degree.

The figure below presents the age of all regulations referred to.

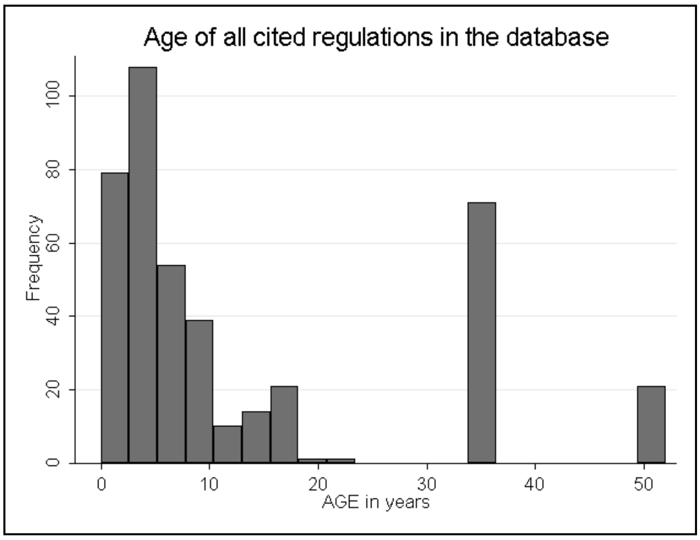

Figure 1: Absolute frequency diagram of all cited regulations in the database

The approximately 20 quoted regulations dating back 52 years, are related to the German Water Pollution Control Act (WHG) from 1957, which is of the end-of-pipe type. The large column at an age of 35 years contains the German Federal Immission Control Act (BImschG) from 1974. The largest column contains, among other guidelines, the RoHS and the WEEE guidelines from 2005, which are of the circular-flow-economy type. The second largest column which contains approximately 80 citations includes amongst other regulations (like for instance the EURO 5 emission standard for cars) the REACH directive from 2007, which is a very new end-of-pipe regulation. A major part of the two columns between ages of five up to ten years accounts for climate policy regulations, like the Energy Saving Act (EnEV) from 2002.

5 Estimation strategy

This paper analyses whether there are long term impacts of environmental regulation on eco-innovation, and whether the impact of the four phases or types of environmental regulation (defined in section three) differs by type of corporate eco-innovative activities. To consider these central research questions, we use a sub-sample of 419 Mannheim Innovation Panel 2009 companies, which introduced or adopted innovations with positive impact on the environment. Note that these innovations were imposed just because companies were forced to innovate by environmental regulation. The dependent variables for nine different environmental benefits of innovations (ECOINNO), are, however, not continuous variables. They measure the amounts of environmental benefits of innovations in an ordered scale ranging from no innovation with environmental benefits ($j = 0$), innovation with low ($j = 1$) and medium ($j = 2$) environmental benefits, up to innovation with high environmental benefits ($j = 3$). Therefore, the regression takes the following form:

$$\text{ECOINNO}_i^* = \boldsymbol{\beta}'\mathbf{P}_i + \delta \ln\left(\text{AGE}\right)_i + \gamma Z_i + \boldsymbol{\lambda}'\mathbf{C}_i + \varepsilon_i \quad (1)$$

$$\text{ECOINNO}_i = j \quad \text{if} \quad \alpha_{j-1} < \text{ECOINNO}_i^* \leq \alpha_j \quad (2)$$

where $j = 0,1,...,m$ and $m = 3$. The α's are unknown parameters and represent the threshold values for moving from one category of environmental benefits of an innovation to another. They were estimated together with the other coefficients.

The vector **P** represents a set of three dummy variables for the three policy phases or types already defined (end-of-pipe (T_EOP), circular-flow-economy (T_CFE), and climate policy (T_CPO)). Also the year of the coming into force of the mentioned regulations was used to calculate their age (not the age of the policy phase). As pointed out in the introduction, we expect long-term impacts of environmental regulation. Accordingly, the age variable ln(AGE) which represents the natural logarithm of the age of the respective regulations is a further regressor of interest. In addition the ln(AGE), Z is a dummy variable related to the regulations' age. Both, the construction of the age variable and the related dummy will be discussed in detail in the next paragraph. The vector **C** represents further control variables, including a set of industry dummies, company size and a dummy for firms in the Eastern part of Germany. The control variables will be discussed later in the corresponding paragraph. Finally, ε represents unobservable impacts on the amount of environmental benefits of introduced innovations.

Since the dependent variables are in ordinal scale, the model described above is estimated using an ordered probit. The use of the ordered probit model requires the assumption of standard normally distributed unobservable factors ε. Furthermore, it relaxes the assumption of a logit or ordered logit model that unobservable impacts on the dependent variable are uncorrelated over its different categories. We think this flexibility is needed since the categories of having introduced innovations with a certain amount of environmental benefits are likely to be affected by other unobservable factors. Such unobserved factors are, for instance, the age of the corporate capital stock or financial constraints, which are possibly correlated with the amount of environmental benefits of introduced innovations or adopted technologies.

Construction of the age variable

The age of the cited regulations was calculated by using the year in which the original version of the regulation came into force. If companies referred to a special amendment of the regulation, this date was used instead. The oldest regulation was used if more than one regulation was cited. In 23 out of 419 observations, companies referred to regulations from 2009 (i.e. the euro-5 emission standard) forcing them to introduce innovation. The age variable is zero in these cases. At the same time, companies also referred to very old regulations (i.e. water pollution regulation from the 1950s, where still no adjustment exists). In order not to overestimate these very old regulations, rearranging the age data by calculating the logarithm seems to be useful. But this rearrangement causes a problem. Calculating the logarithm of the age zero observations is not possible and we would end up in loosing these 23 observations. For this reason, we rearranged the data as follows: $\ln\_AGE = \ln(AGE + e) - 1$ where ln_AGE is the new variable of interest and AGE represents the true age of the respective regulation. This rearrangement ensures that the regulations from 2009 with a true age of zero also have a value of zero after the manipulation. But in order to address the fact that also innovation were introduced due to regulation enacted in 2009, we introduce a dummy variable with the value of one for this cases and zero otherwise. Hausman et al. (1984) used a similar solution to tackle with the "zero value problem" but for a dependent variable with zero values. In the present paper the "zero value problem" occurs for an independent variable.

The logarithm of the age variable is also useful because a linear relationship between the age of the regulation and innovative incentives seems less reasonable. The logarithm version suggests that the incentive to introduce a technology because of regulative constraints increases with age but the additionally incentive declines for every further year. We also tested a linear and quadratic term of the age variable together. If the coefficient of the quadratic term would be negative such a functional form would imply increasing innovative incentives with increasing age until a peak is reached. For older regulations, incentives to innovate would decrease. We expected this case to be the most reasonable one but found no significant evidence for such a case at all. For this reason, we employ the logarithm version since it allows at least decreasing "marginal incentives" of the age of regulation. The use of the linear term would mean to assume unrealistic proportional increasing incentives with the age of regulation. To sum up, the age of the regulation and the type of regulation serves as our regressors of main interest in the estimation.

Control variables

Other control variables will be used in the model to control for other impacts on the amount of environmental benefits of introduced innovation. These are the logarithm of the company size, a dummy for the Eastern part of Germany and various industry dummies. The size variable addresses the assumption that large companies tend to engage more often in innovative activities (Schumpeter, 1942). Furthermore, by assuming that larger companies may produce more standardised products with help of more capital intensive production techniques, it can be assumed that these production technologies cause more pollution. Thus, if there are strict environmental standards, larger firms have more incentives to abate pollution by introducing environmental technology. The model also contains a dummy with value one for firms located in the eastern part of Germany.

In addition to the size variable, sector dummies are used to control for sector specific unobserved cross-sectional differences. The sector dummies represent one-digit NACE codes. NACE 0 (agriculture, fishing, and forestry) is not covered in the MIP. Furthermore, NACE 1 serves as the reference category and is omitted. Because of few observations available, NACE 9 is matched with NACE 8.

Is there a problem of omitted variables? Since this paper deals with innovation impacts of regulation one might argue that R&D expenditures also need to be considered. But as mentioned before the CIS measures adoption/diffusion of innovation so that the paper focuses on the adoption of environmental technology due to regulation constraints. Therefore, controlling for R&D would provide little insights. In addition to this, we only considered observations, in which companies stated regulations to be responsive for introduced innovations. This means that we do not consider a choice decision to invest in environmental R&D or not. We take the decision that environmental technologies are adopted due to regulative constraints as fact.

6 Results

The empirical results are listed in table 3 below.

Table 3: Estimation results (ordered probit model)

VARIABLES	a I_MAT	b I_ENE	c I_CO2	d I_AIR	e I_H2O	f I_SOI	g I_NOI	h I_DAN	i I_REC
T_EOP	0.163	0.182	0.164	0.171	0.522*	0.167	0.437*	0.244	0.382*
	(0.192)	(0.189)	(0.195)	(0.213)	(0.209)	(0.230)	(0.205)	(0.198)	(0.189)
T_CFE	0.0134	-0.330	-0.252	-0.742**	0.00673	-0.0904	-0.0701	0.602**	0.510**
	(0.184)	(0.181)	(0.186)	(0.203)	(0.195)	(0.217)	(0.194)	(0.191)	(0.182)
T_CPO	0.187	0.618**	0.688**	0.294	0.0573	-0.116	0.204	-0.353	-0.00198
	(0.208)	(0.205)	(0.209)	(0.223)	(0.223)	(0.246)	(0.219)	(0.219)	(0.204)
ln_AGE	0.0637	-0.000171	0.239**	0.251**	0.372**	0.299**	0.204*	-0.274**	0.0704
	(0.0811)	(0.0777)	(0.0801)	(0.0809)	(0.0827)	(0.0877)	(0.0819)	(0.0836)	(0.0772)
zero_dummy	0.206	0.283	0.844**	0.743**	0.161	0.201	0.383	-0.594*	0.376
	(0.279)	(0.267)	(0.268)	(0.271)	(0.315)	(0.333)	(0.277)	(0.298)	(0.261)
ln_SIZE	0.170**	0.161**	0.136**	0.144**	0.102**	0.0650	0.0919**	0.107**	0.0264
	(0.0327)	(0.0330)	(0.0322)	(0.0332)	(0.0345)	(0.0363)	(0.0333)	(0.0339)	(0.0311)
EAST	0.0797	-0.142	-0.113	-0.164	-0.0834	-0.0801	-0.150	-0.206	-0.0374
	(0.126)	(0.120)	(0.124)	(0.128)	(0.136)	(0.146)	(0.131)	(0.131)	(0.119)
sector dummies	yes	yes	yes	yes	yes	yes	yes	yes	yes
Constant									
α_1 (cut_1)	0.313	-0.273	0.585	0.875*	1.117**	1.142**	1.015**	-0.119	-0.320
	(0.323)	(0.319)	(0.322)	(0.340)	(0.343)	(0.368)	(0.334)	(0.338)	(0.317)
α_2 (cut_2)	0.984**	0.498	1.213**	1.472**	1.668**	1.707**	1.652**	0.495	0.458
	(0.325)	(0.320)	(0.325)	(0.343)	(0.346)	(0.372)	(0.338)	(0.338)	(0.316)
α_3 (cut_3)	2.226**	1.412**	2.033**	2.151**	2.372**	2.249**	2.532**	1.251**	1.211**
	(0.337)	(0.324)	(0.332)	(0.350)	(0.353)	(0.381)	(0.353)	(0.341)	(0.319)
Observations	419	419	419	419	419	419	419	419	419
Pseudo-R2	0.0872	0.0769	0.0822	0.0915	0.0869	0.0563	0.0549	0.0888	0.0269
Prob > chi2	0	0	0	0	0	0.000146	2.84e-06	0	0.00584

Standard errors in parentheses
** p<0.01, * p<0.05
Includes seven sector dummies based on NACE one-digit level industries

The results point out that the study is able to identify long-term impacts of environmental regulation on innovation for five out of nine cases of environmental related innovation. In detail, the age variable (ln_AGE) provides strong significant positive impact on innovations with positive benefits on CO_2 emission (c), other air pollutants (d), water pollution (e), soil pollution (g), and finally weak significance for noise burdens (g). But these findings cannot be treated without some scepticism. Especially for innovation reducing water pollution, this finding is still biased because water pollution control regulations are just old. However, a strong significant negative impact was identified for innovation related to a reduction of hazardous inputs. Energy efficiency regulation and also material efficiency regulation are of more recent date which may lead to the outcome of no impact of the age variable. Although recycling improvement regulations were introduced in 1990s, the time variable was found to be insignificant. Such a result of no long term effects of this type may be biased due to the very often cited new RoHS guideline from 2005 within this policy type.

In contrast to the hypothesis of long-term effects triggered by regulations, the hypothesis that environmental innovation is triggered by different policy phases cannot be confirmed in general. Surprisingly, the class of end-of-pipe regulations only has weak impacts on innovation for a reduction of water pollution (e), noise reduction (g), and on improvement of recycling (i). One reason for this outcome, especially for its impact on innovation for reducing water pollution could be that German end-of-pipe regulations often deal with water pollution control (Jänicke et al., 2003). In contrast to these findings, the results indicate significant impact of the circular flow economy type on the innovation, resulting in positive benefits for improving recycling possibilities and a reduction of hazardous input use. This policy types also have a negative significant impact on innovation related to air emission reductions. This can be explained by the fact that cleaner production measures often reduce energy and material use, but they do not, on the other hand, necessarily lower air emissions. The results for the climate policy type indicate strong support for the idea that innovation related to increase energy efficiency or to reduce CO_2 emissions is triggered by this policy phase or type.

Company size as a control variable for cross-sectional differences in corporate size is a factor of some importance, especially with regard to the adoption of innovations. Company size has a strong positive impact for almost all environmental benefits except for innovation related to benefits on soil and noise burdens. A possible reason for this finding could be that larger companies tend to engage more in capital intensive large scale production, which can be assumed to be more pollution intensive than small scale production. Consequently, these companies might be more affected by environmental regulation than smaller ones. The dummy for the Eastern part of Germany has no significant impact at all. Since the sector dummies are only used to control for possible heterogeneity related to differences in the stringency of regulation across sectors, they are not presented in the results but included in the regression.

Finally, some words of caution should be addressed at this point. The findings of the study should also be treated with some scepticism. The goodness of fit value of all tested cases of environmental related innovations turns out to be very low. A reason for this is surely that only observations are considered if companies report that innovations were introduced due the corresponding regulations. But suppose for instance, the case in which a company reported that innovations were triggered by say recycling standards. If this company also introduced for instance energy saving innovations, the determinants of these innovations are omitted, and without any doubts, they are others than for the innovations for improving recycling. This problem could be one reason for the weak performance of the policy type variables, or even for the negative impact of some policy phases or types on innovation related to completely different environmental benefits.

7 Conclusion

This paper investigated two central questions. First: the question whether there are long-term effects of environmental regulation on innovation with environmental benefits and second: whether different types of environmental policy differ in their impact on several environmental benefits of triggered innovations.

The present paper addressed both research questions by relying on MIP data from the 2009 survey where firms are asked to cite the regulations to be responsive for introduced innovations with environmental benefits.

In order to shed light on the first question of interest, the age of the respective regulations was calculated. The ordered probit regression results support this hypothesis for the majority of environmental benefits of innovations. However, the results do not provide proof for environmental benefits in cases of material use and energy efficiency, or for compensation of dangerous inputs and improvement of recycling possibilities.

The second question regarding the impact of different phases of environmental policy on environmentally related innovations was approached by categorizing regulations into three different policy phases or types: end-of-pipe, circular-flow-economy, and finally, climate-policy regulations. This classification represents a content-based and temporal order. These environmental regulation types were expected to differ in their influence on triggering innovation by means of several environmental impacts. Considering the results, this hypothesis does not hold in general. But some evidence was found that there is a significant effect of all policy phases or types on innovation with strong related environmental impacts. However, the significance of the results for the end-of-pipe regulation is weak.

Nonetheless, the estimation of long-term effects of environmental regulation on environmentally related innovations provide some insights that even very old regulations have triggered such innovation until today. Thus, command-and-control regulations, to which the overwhelming majority of regulations cited in our database accounts for, provide long term incentives to innovate. In this sense, our results are somewhat surprising since command-and-control regulation is expected to offer no or at least little dynamic incentives to innovate or adopt new technologies.

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