Chapter 8
Environmental Policy and Induced Technological Change in European Industries

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Abstract The study provides an empirical analysis of the effects of environmental policy on technological innovation in a specific field of environmental technologies. The econometric analysis is based on information on innovation activities deriving from various Community Innovation Survey waves and information on environmental accounts (NAMEA) for a large set of European industries. The empirical results show the existence of a robust enhancing effect played by environmental policy with respect to energy and resource efficiency innovations. In addition, the introduction of energy and resource efficiency technologies is found to be positively associated with innovative investment and to be strictly related to improved product quality. These results proved to be robust to the use of alternative proxies of the stringency of environmental policy and to the introduction of different control variables in different model specifications.

Keywords Induced technological change • Environmental policy • European industries • Community innovation survey • NAMEA

8.1 Introduction

The introduction of policy measures that aim to reduce the environmental impact of economic activity has been traditionally seen as being potentially harmful to economic performance due to the consequent increase in production costs. However, it has been argued that stringent environmental regulations may induce flows of innovations by generating an expansion of markets for environmental protection technologies.

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The origins of this argument can be identified in the work of Schumpeter who highlighted the importance of external pressures, i.e. forces outside the economic system, in shaping the economic activity (Schumpeter 1939, 1947) and in the literature on the induced innovation hypothesis first advanced by Hicks (1932), who studied the impact of changes in relative prices of production factors on technological change directed to economise the use of the factor of production which has become relatively more expensive.

More recently, the debate has been revived by the work of Porter and van der Linde (1995) who stated that the shock produced by new regulations creates external pressure on firms that are fostered to create new products and processes that positively affect the dynamic behaviour of the economy and hence its competitiveness.

Many empirical studies have analysed the effects that environmental policies have on innovation and competitiveness by adopting alternative hypothesis and different empirical models. Two major research areas have been explored. The first directly analyses the relationships between regulation and environmental policies on innovation activities (Jaffe and Palmer 1997; Jaffe et al. 2005; Popp 2006, among others)[1]; the second is oriented towards investigating the effects of environmental regulation on international competitiveness and only indirectly on induced technological change (Jaffe et al. 1995; Harris et al. 2002; Van Beers and van den Bergh 2003; Wagner 2006; Costantini and Crespi 2008, 2011).

This chapter aims to contribute to the first stream of empirical literature which has not completely succeeded in finding robust evidence on the impact of environmental policy on the introduction and diffusion of green technologies. This unsatisfactory result is mainly due to the limited availability of reliable indicators of both regulation and environmental innovations (Del Rio Gonzalez 2009). In this respect, the evidence presented here is based on a novel dataset that gathers data from the Community Innovation Survey (CIS) and the national accounting matrix including environmental accounts (NAMEA) for selected European countries at the sectoral level. In particular, the CIS appears to be an appropriate source of information for the investigated issue since it provides a more direct measure of innovation performance than traditional indicators such as R&D and patent data and allows for a more thorough investigation of the determinants of innovation (Archibugi and Pianta 1996; Crespi and Pianta 2008; Rennings and Rammer 2009). On the other hand, information gathered from NAMEA can be used to build sector-based proxies for the stringency of environmental regulation (Costantini et al. 2012).

[1] See also recent contributions to the special issue "Laws, Regulation and New Product Development – the Role of the Regulatory Framework for the Management of Technology and Innovation", *International Journal of Technology, Policy and Management*, Vol. 11, Nos. 3/4, 2011.

8.2 Theoretical Background and Empirical Issues

The core theoretical foundations of the relationship between environmental policies and technological innovation can be identified in three fundamental contributions to the economic literature: the Hicksian theory of induced technical change, the notion of creative response introduced by Schumpeter and the demand-pull hypothesis proposed by Schmookler.

Building on work by Marx (1867), Hicks (1932) clearly analyses the link between changes of relative prices and technical innovation, paving the way to a tradition of analysis that focuses on the role of changes in the prices of production factors in inducing technological innovations (Antonelli and Scellato 2011). When an input becomes relatively more expensive, there is an incentive for its substitution at the margin with other factors of production so that firms are induced to adopt or to develop new technologies that reduce the use of that input. In this context, environmental policies spur innovations in green technologies that are capable of delivering the same products with less environmental damage.

Such an intuition can be better qualified in the economics of innovation framework, where it is crucial to mark the distinction between the types of reactions firms may have in response to changing external conditions. Following Schumpeter's (1947) seminal contribution, we can distinguish between adaptive responses which consist of standard price/quantity adjustments that fall within the range of existing practices and creative responses, i.e. innovative changes that occur when some firms in an industry do something outside the range of existing practices. Moreover, the theory of induced technical change may help to understand the supply side of regulation effect on innovation. However, regulation has the additional potential to increase demand for new products and open up new markets. The relevance of this effect is clearly stated by Schmookler (1966) who emphasises the importance of demand dynamics in influencing the investment in inventive activities and the direction of innovative efforts across products and industries. Schmookler's path-breaking contribution was an attempt to demonstrate the economic nature of technological change by claiming that demand conditions crucially influence the desirability and development of inventions and that the existence of an expected profitability and expansion of market demand represent the key stimulus to which inventive activities react (Mowery and Rosenberg 1979; Scherer 1982; Kleinknecht and Verspagen 1990; Crespi and Pianta 2007).

Such arguments seem to be particularly relevant to environmental innovations. Indeed, due to negative external effects associated with the majority of environmental issues, environmental innovations are at least less market-driven than other innovations so that environmental policy becomes one of the main drivers of environmental innovation (Horbach 2008). The shock produced by a new environmental regulation may create external pressure on firms that are fostered to generate new products and processes. Its stringency may represent a high influential determinant of the rate and direction of environmental technological change. However, the empirical studies did not completely succeed in finding robust support for the hypothesis of a positive relationship between environmental regulation and innovation. One of the explanations for this unsatisfactory result is the existence of poor indicators of both regulation and environmental innovations (Kemp and Pearson 2007; Del Rio Gonzalez 2009).

Regarding the latter, many variables have been used as a proxy for environmental technological change, including patent data, investments in environmental protection, environmental R&D investments and the adoption of specific technologies. However, measuring technological change is a particularly difficult task. Innovation depends on a variety of activities ranging from formalised R&D to production engineering. Organisational innovations and different forms of soft innovations are also relevant. Moreover, the introduction of innovations does not follow a linear process from R&D activities to the eventual commercialisation of new products (Archibugi and Pianta 1996).

The most used innovation input and output indicators have been subject to much criticism (Sirilli 1999). On the one hand, the growing literature on innovation indicators has shown that the resources devoted to R&D represent only one source of innovation and that other innovation inputs might be relevant but are not easily measurable. On the other hand, not all inventions are patented because firms often protect their innovations with alternative methods, typically through industrial secrecy.

Moreover, firms differentiate their patenting strategies depending on their expectations for exploiting their inventions commercially in domestic or international markets. However, each patent office has its own institutional characteristics which affect the costs, length and effectiveness of the protection accorded. In turn, this may crucially influence inventors' interest in applying for patent protection.

The full recognition that innovation is a highly differentiated phenomenon that is associated with diverse strategies of firms and characterised by remarkable industry and country specificities has led researchers to try to overcome the limitations of highly imperfect proxies such as R&D expenditures and patents. In this respect, the availability of CIS has opened up a great opportunity for detailed investigations of the variety of innovation processes.

This source of data has provided researchers with new information on the innovative efforts of firms and the diverse strategies that lead to the introduction of new products, new processes and new organisational behaviours. Moreover, the CIS have given us a deeper understanding of the factors hampering and easing innovation along with the possibility to graft the economic effects of innovative activities better.

Another major problem in all analyses of the relationship between environmental policy and technological change is the measurement of environmental policy stringency. Environmental policies can be highly differentiated across countries and sectors and are not therefore directly comparable. Moreover, publicly available data on regulation stringency are scarce and are not collected in a coordinated manner in different countries, thereby limiting cross-country comparisons.

Since it is very difficult to obtain data on the stringency of environmental policy, some authors have proxied this with total abatement expenses per sector or firm

(Jaffe and Palmer 1997). However, the amount of expenses might be affected by other variables and not necessarily by the ambition of environmental regulation. Alternatively, emissions (typically of CO_2) can be considered an indirect proxy of environmental standards because if a country is applying stringent and efficient environmental regulation, the level of emissions will be lower. Moreover, gas emissions are closely related to the Kyoto Protocol commitments, thus representing a valuable proxy variable that gives an approximation of countries' efforts to respect Kyoto abatement targets (Costantini and Crespi 2008).

8.3 Data Description

In this chapter, the complex nature of innovation processes and the role of differentiated innovation strategies across firms, sectors and countries are fully recognised. Such complex forms of innovative activities can hardly be described by traditional indicators such as patents and R&D. Therefore, an important feature of this analysis is the use of more specific measures of innovative performance, drawn from innovation surveys which account for the variety of the determinants and outcomes of innovation (Archibugi and Pianta 1996; Sirilli 1997, 1999).

Moreover, we adopt a sectoral perspective to the analysis of the relationship between environmental policy and innovation since we claim that the specific characteristics and structure of sectors affect the rate and direction of environmental technological change. As emphasised by Malerba (2004, p.380) among others, "Innovation greatly differs across sectors in terms of characteristics, sources, actors involved, the boundaries of the process, and the organization of innovative activity". At the industry level, empirical analyses show that sectors differ in their returns from R&D investments and innovative efforts (Crespi and Pianta 2007, 2008; Bogliacino and Pianta 2011); this reflects the existence of different scientific and technological opportunities and the presence of R&D spillovers. These specificities have led to the conceptualisation of technological regimes and sectoral systems of innovation which explain the differentiated effect of R&D and innovative efforts on different performance measures across industries (Breschi et al. 2000; Malerba 2004). Furthermore, the sectoral approach has the advantage of allowing for the integration of different data sources. In particular, the database developed for the empirical analysis merges information on innovation activities deriving from the CIS with that contained in the NAMEA accounts and is articulated as follows.

The database used for addressing the determinants of technological change is based on the Urbino Sectoral Database which integrates and elaborates data from national sources of three editions of the Community Innovation Survey (CIS 2, reference period 1994–1996; CIS 3, reference period 1998–2000; CIS4, reference period 2002–2004). The Urbino Sectoral Database includes data on innovation indicators for 8 European countries – Germany, France, Italy, Norway, the Netherlands, Portugal, Spain and the United Kingdom. The original database uses the NACE Rev.1 industry classification at the 2-digit level of aggregation and covers 22 manufacturing sectors and 17 service industries. However, given data limitations in environmental accounts for service industries, this analysis is confined to manufacturing industries.

The variables considered in the database allow for an in-depth analysis of the many dimensions of innovation. These include the many facets of innovation activity and the technological collaboration involved in this activity, the innovation inputs, especially non-R&D inputs, the innovation outputs, the sources of information relevant to innovation and its objectives, the funding of innovation, the many possible obstacles to innovation, its protection methods and several important dimensions of strategic and organisational change.

For our purposes, the most relevant information contained in the CIS regarding environmental innovation is a general question on the introduction of innovation aimed at reducing environmental damage and a more specific question to firms which asks whether they introduced innovations in order to reduce material and energy consumptions. This kind of innovations is classified according to Rennings and Rammer (2009) as energy and resource efficiency innovations (EREIs) and may be regarded as a share of all environmental innovations. Examples of EREIs are new products that require fewer raw materials or energy as well as new products that reduce the amount of material and energy needed during their use or modify production or distribution methods. In the empirical analysis, we will focus on this specific aspect for three main reasons. First, as will be further discussed, the main proxy used for environmental regulation will be CO_2 emissions which are particularly related to energy consumption. Second, as shown by Horbach et al. (2011), EREIs represent the most relevant area of innovation with environmental benefits. Finally, the choice of focusing on EREIs allows us to test the relevance of regulation on a specific kind of environmental innovation which, in contrast to others, is – at least partially – a private good since it reduces the costs related to the use of energy and materials. Thus, we may well expect there should be some private incentives for innovators to take energy and resource efficiency measures (Corradini et al. 2011). In this respect, a test on the relevance of the inducing role of environmental policy for this specific case appears to be of particular interest since it may confirm the strength of the regulation channel also in the presence of limited private incentives to reduce environmental impact through innovation.

In more detail, the survey asked about the importance of cuts in material or energy costs per unit as an effect of innovations that had been introduced in the survey reference period. The extent of effects is measured on a four-point Likert scale (ranging from *not relevant* to *low* and *medium* to *high*). In the Urbino Sectoral Database, the relevant variable considers the share of firms stating that for at least one innovation introduced in the reference period such effects were *medium* or *high*.

Figure 8.1 shows the percentage of firms who declare they have introduced EREIs in the period 2002–2004 for the pool of considered countries and each manufacturing sector. The coke, refined petroleum products and nuclear fuel sector have the highest share of companies introducing EREIs. This innovation effect is

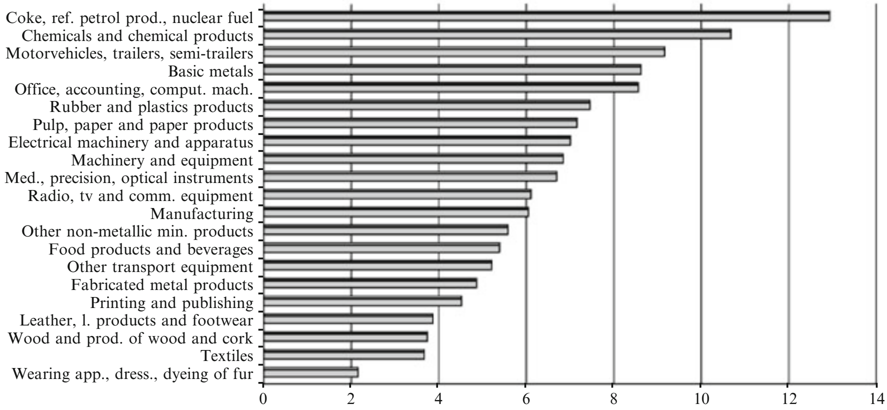

Fig. 8.1 Share of energy and resource efficiency innovating firms in European industries (2002–2004) (Source: Urbino Sectoral Database)

particularly relevant also in the chemical and chemical product, motor vehicle and basic metal sectors. In industries related to clothing, textile leather products and wood products, on the other hand, EREIs are less relevant.

In the empirical analysis, environmental policy is proxied by data on gas emissions, since their dynamics in part reflect the stringency and the efficiency of environmental regulation (Costantini and Crespi 2008). Emission data are based on the NAMEA approach available from EUROSTAT (de Haan and Keuning 1996).

We use NAMEA tables for the 8 EU countries covered by innovation data over the period 1996–2006, with a 2-digit Nace (Rev. 1.1) disaggregation level. In the NAMEA tables, environmental pressures and economic data (output, value added, final consumption expenditure and full-time equivalent employees) are assigned to the economic branches of resident units or to the household consumption categories directly responsible for environmental and economic phenomena. The advantage of using environmental accounting data comes from the internal coherence and consistency between economic and environmental modules and the possibility to consistently merge different sources of information (in our case, on innovative activities) at the sectoral level (Marin and Mazzanti 2011).

More specifically, the information drawn from the NAMEA for the present analysis is related to the dynamics of CO_2 emissions (the main greenhouse gas emissions responsible for climate change) and air pollutants responsible for the acidification process.[2] In this way, we can take two main themes in environmental policy into account: greenhouse gas emissions (GHG) and the acidification process (ACID). The first are more globally distributed and are mainly regulated within the

[2] Data on emissions of different pollutants have been aggregated according to their potential acid equivalent (PAE), allowing us to obtain a synthetic indicator of acidification. According to standard classification, the weights used for the aggregation process are the following: 1/46 (NOx), 1/32 (SOx) and 1/17 (NH3).

Kyoto policy framework. ACID emissions are more localised, and their relevant reduction observed in the last two decades appears to be associated with the role played by exogenous regulative factors (Marin and Mazzanti 2011).[3]

8.4 The Econometric Model

Building on previous analyses (Crespi and Pianta 2007, 2008; Rennings and Rammer 2009; Bogliacino and Pianta 2011), we aim to test the relevance of the inducement effect of environmental policy on EREIs by controlling for a number of specific factors that are likely to affect the innovative performance of firms and industries. Hence, the approach proposed here combines several of the analytical perspectives previously examined, since it argues that innovation at industry level is the result of both technology push factors, qualified with the variety of sources, nature and strategies for innovation and of the pulling effect of environmental policy.

Considering knowledge-based factors, we assume a view of innovation where the sources of knowledge are present both within the innovating firm – reflected in its patenting and R&D activities – but also emerge from the interaction and cooperation between firms and organisations where distributed and localised knowledge may be gathered and recombined, leading to new technological advances (Coombs and Metcalfe 1998; Antonelli 2008). Moreover, the development of new production processes with the acquisition of new machineries linked to innovation and a strategy aiming at increasing product quality through innovation are expected to be associated with the introduction of energy and resource efficiency innovations (Rennings and Rammer 2009).

The proposed model can be synthesised as follows:

$$\mathrm{EIN}_{ijt} = \alpha\mathrm{INP}_{ijt-1} + \beta\mathrm{STR}_{ijt-1} + \mu\mathrm{KNO}_{ijt-1} + \gamma\mathrm{REG}_{ijt-1} + \lambda\mathrm{IE}_{ij} + \mathrm{e}_{ijt} \qquad (8.1)$$

where for time t, sectors i, countries j:

- EIN represents our *environmental innovation* variable: the share of firms that have introduced energy and resource efficiency innovation.
- INP refers to *innovation input* variables: the percentage of firms with R&D activities and the percentage of firms that acquired new machinery and equipment linked to innovation.

[3] In Europe and North America, acidification has led to several international agreements including the Convention on Long-Range Transboundary Air Pollution (1979) and its protocols to reduce emissions of sulphur (Helsinki 1985, Oslo 1994, Gothenburg 1999), nitrogen oxides (Sofia 1988, Gothenburg 1999), VOCs (Geneva 1991, Gothenburg 1999) and ammonia (Gothenburg 1999). Two other protocols aim to reduce emissions of heavy metals (Aarhus 1998) and persistent organic pollutants (Aarhus 1998). Moreover, many regulatory interventions on air pollution and the adoption of end-of-pipe technologies have been introduced by the EU since the early 1980s (e.g. Directive 1980/779/EC replaced by the 1999/30/EC, the Directive 1999/32/EC and the Clean Air for Europe programme from 2005).

Table 8.1 Description of variables

Label	Definition of variable	Source
EIN	Share of firms introducing EREIs	CIS
R&DINT	Share of firms with research and experimental development within the enterprise	CIS
MACHINERY	Share of firms with acquisition of machinery and equipment linked to innovations	CIS
COOPERATION	Share of firms with cooperation arrangements on innovation	CIS
PATENTS	Share of firms with patent applications	CIS
R&DEXT	Share of firms with acquisition of R&D services	CIS
INN.TURN	Share of turnover due to new products	CIS
GROUP	Share of firms belonging to a group	CIS
STANDARD	Share of firms fulfilling regulations and standards	CIS
QUALITY	Share of firms improving product quality	CIS
VAR.CO_2	Compound annual rate of change in CO_2 emission intensity (CO_2/value added at constant prices)	NAMEA
VAR.ACID	Compound annual rate of change in acid emission intensity (acid/value added at constant prices)	NAMEA

- STR includes variables related to *innovation strategies*: the percentage of firms that aim to increase product quality; output indicators identifying a strategy of *technological competitiveness* such as the share of firms with patent applications and the share of innovative sales on total turnover (Crespi and Pianta 2007, 2008).
- KNO is relative to *external knowledge sources*: the percentage of firms with cooperation arrangements for innovation and the percentage of firms belonging to a group.
- REG represents *regulation variables*: the share of firm that introduces innovations to fulfil regulations and standards, the rates of growth of emission intensity both in terms of CO_2 emissions and aggregated potential acid equivalent.
- IE is the individual fixed effect.
- e is the error term.

The periods of reference for CIS data are 1994–1996, 1998–2000 and 2002–2004; regulation variables based on NAMEA data are calculated as the compound annual rates for the three intervals 1996–1998, 1998–2000 and 2002–2004 (Table 8.1 for detailed variables description). As indicated in the model specification, all covariates are introduced in the model with one lag in order to reduce potential endogeneity problems related to reverse causality.

Since lower levels of CO_2 emissions are a proxy of more efficient environmental regulation, a negative coefficient associated with CO_2 emissions is expected. This can be interpreted as an indication of the existence of a positive effect of regulation on the introduction of energy and resource efficiency innovations.

As reported in the model equation, country and industry individual effects are included in the analysis in order to account for the importance of national macroeconomic contexts and the relevance of country and sectoral specificities. Such an approach is also supported by the comparative analysis of the fixed effects (FE) and the random effects (RE) estimators by means of the Hausman test which suggests that the FE is the most appropriate estimator for our model.

8.5 Empirical Results

Table 8.2 presents the results of econometric estimates obtained through the fixed effect panel estimator where environmental regulation is proxied by the lagged rate of growth of CO_2 emissions in each sector of economic activity. At the sectoral level, this variable represents an indirect measure of environmental policy stringency mainly related to the achievement of Kyoto targets.

We started with a parsimonious specification (Model 1) in which the share of firms introducing EREIs in each sector is found to be positively and significantly affected by two innovative indicators, the acquisition of new machinery linked to innovation

Table 8.2 Environmental regulation (CO_2 emissions) and energy and resource efficiency innovations (fixed effect estimator)

Variables	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)
L.VAR.CO_2	−0.145**	−0.148**	−0.127**	−0.152**	−0.152**	−0.219***
	(0.066)	(0.061)	(0.063)	(0.062)	(0.062)	(0.066)
L.MACHINERY	0.261**	0.179*	0.230**	0.034	0.028	−0.216
	(0.105)	(0.095)	(0.088)	(0.115)	(0.121)	(0.161)
L.QUALITY	0.277***	0.301***	0.197**	0.141*	0.139*	0.195**
	(0.071)	(0.100)	(0.075)	(0.075)	(0.077)	(0.089)
L.R&DINT	0.005					
	(0.130)					
L.R&DEXT		0.424**				
		(0.170)				
L.STANDARD		−0.143				
		(0.146)				
L.PATENTS			0.384**	0.353**	0.353**	0.783**
			(0.164)	(0.158)	(0.159)	(0.344)
L.COOPERATION				0.592**	0.597**	0.819***
				(0.239)	(0.242)	(0.289)
L.GROUP					0.031	
					(0.153)	
L.INN.TURN						0.188
						(0.263)
CONSTANT	−10.48***	−10.76***	−10.76***	−9.97***	−10.79**	−16.78***
	(3.779)	(3.213)	(3.237)	(3.126)	(5.186)	(6.059)
Observations	221	220	217	217	217	197
R-squared	0.465	0.518	0.495	0.541	0.542	0.566

Robust standard errors in parentheses, ***$p < 0.01$; **$p < 0.05$; *$p < 0.10$

and the share of firms aiming at improving product quality. This result is consistent with previous literature which showed that many environmental innovations combine an environmental goal with a benefit for the firm or user (Kemp and Arundel 1998; Rennings and Zwick 2002). It also reveals that successful resource efficiency efforts also tend to modify product characteristics. More efficient processes have to meet higher quality standards, hence improving product quality (Rennings 2009). Moreover, the empirical evidence suggests that adapting processes to higher levels of resource efficiency is associated with the introduction of new machinery and equipment with a higher level of energy or material efficiency.

The positive effect of the third innovation variable – the share of firms with internal R&D activities – is not statistically significant. As will be further discussed, this result does not imply that scientific and technological knowledge is not relevant for the introduction of EREIs but probably reflects a limited explanatory power of the used variable.

In parallel, the variable associated with environmental regulation is statistically significant and shows the expected negative sign. The higher the decline in CO_2 emissions, the stronger the stringency of environmental regulation is likely to be and the higher the share of environmental and resource efficiency innovators.

In order to test the robustness of the identified relationship between regulation and innovative activities, we estimated a set of different models including other relevant control variables. In Model 2, the share of firms acquiring external R&D in each sector has been introduced as an alternative covariate capable of capturing structural innovative investments that characterise different industries. In addition, the relevance of a more general variable related to regulation (i.e. the share of firms aiming at fulfilling regulations and standards through innovation) was tested. The estimated model suggests that the alternative R&D variable has a greater discriminatory power than the previous one, indicating a positive effect of external technological knowledge related to the acquisition of R&D performed outside the company on the dependent variable. Moreover, the coefficient associated with our specific regulation variable is confirmed to be statistically significant and with the expected sign. Interestingly, the general regulation variable directly derived from the CIS questionnaire does not significantly enter the model. This may be the result of the very broad definition of this variable that includes innovation effects associated with every kind of regulation and standard, which contrasts with the high specific definition of the dependent variable.

In Models 3–6, other covariates are tested in order to offer further robustness checks to previous results. In these models, in particular, the internal generation of technological knowledge is captured through an indicator of patent activity performed by firms in different sectors. In parallel, the external knowledge sources are proxied by the variable associated with cooperation activities linked to innovation and by the indicator measuring the share of companies belonging to a group. Finally, Model 6 also controls for the share of innovative turnover over total sales as a further indicator of sectoral innovative performance.

As a general result, the identified relationship between the proxy for environmental policy mainly related to the achievement of Kyoto targets and innovation activity in the field of energy and resource efficiency turns out to be robust to the

Table 8.3 Environmental regulation (acidification) and energy and resource efficiency innovations (fixed effect estimator)

Variables	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)
L.VAR.ACID	−0.074*	−0.073*	−0.071	−0.091**	−0.091**	−0.130***
	(0.042)	(0.040)	(0.044)	(0.043)	(0.043)	(0.048)
L.MACHINERY	0.245**	0.159	0.204**	−0.001	−0.003	−0.246
	(0.111)	(0.101)	(0.092)	(0.122)	(0.127)	(0.172)
L.R&DINT	−0.017					
	(0.131)					
L.R&DEXT		0.407**				
		(0.173)				
L.QUALITY	0.278***	0.299***	0.190**	0.131*	0.131*	0.172*
	(0.072)	(0.103)	(0.076)	(0.077)	(0.078)	(0.092)
L.STANDARD		−0.139				
		(0.150)				
L.PATENTS			0.407**	0.383**	0.382**	0.871**
			(0.166)	(0.160)	(0.161)	(0.357)
L.COOPERATION				0.595**	0.597**	0.732**
				(0.243)	(0.246)	(0.295)
L.GROUP					0.012	
					(0.155)	
L.INN.TURN						0.236
						(0.272)
CONSTANT	−9.51**	−10.16***	−10.21***	−9.37***	−9.71*	−16.73**
	(3.822)	(3.305)	(3.294)	(3.187)	(5.342)	(6.290)
Observations	215	214	211	211	211	191
R-squared	0.450	0.499	0.484	0.530	0.530	0.531

Robust standard errors in parentheses, $^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.10$

introduction of different controls. Moreover, both the internal accumulation of technological capabilities and external knowledge sources emerge as factors that are crucial in explaining the environmental innovation performance of industries.

In order to test this evidence further, a different proxy for environmental policy has been applied in all considered models. While the first one was mainly related to the reduction in greenhouse gas emissions, the second one mainly reflects the level of policy stringency linked to the acidification process. In this respect, such a variable appears to be less connected to the energy sector, and therefore, a looser relationship with our dependent might be expected. However, exogenous regulative factors have been seen to play a relevant role in shaping emissions' reduction associated with the acidification process which can be therefore used to proxy the policy attention towards the achievement of environmental targets. For the same reasons, with respect to the specified econometric models, this variable appears to be less affected by potential endogeneity problems, thus providing us with a further robustness control of previous results.

Table 8.3 presents results obtained by estimating the same models discussed in Table 8.2 in which the regulation variable is represented by the lagged compound rate of change in emissions connected with the acidification process. The interpretation of results is straightforward. Although the magnitude of the identified effect is lower than the CO_2 variable, the positive and significant relationship between environmental regulation and the introduction of energy and resource efficiency innovation at the sectoral level is in general confirmed.

8.6 Conclusions

The study has provided an empirical analysis of the effects of environmental policy on technological innovation in a specific field of environmental technologies. The econometric analysis is based on a novel database that merges information on innovation activities deriving from various CIS waves and information on environmental accounts (NAMEA) for a large set of European industries. The introduction of energy and resource efficiency technologies is found to be positively associated with innovative investment (both in terms of acquisition of new machinery linked to innovation and R&D or patenting activities). Moreover, consistently with previous literature, EREIs are found to be strictly related to improved product quality. Finally, the empirical results have demonstrated the existence of a robust enhancing effect played by environmental policy with respect to innovative activities in the considered technological field. Both the two proxies for environmental regulation reflecting the policy domains related to greenhouse gas emissions and the acidification process significantly entered the estimated models. This result proved to be robust to the introduction of different control variables in the different model specifications.

From a theoretical point, this evidence is grounded in the theory of induced technical change that helps to understand the supply side of regulation effects on innovation and in the demand-pull hypothesis that argues that regulation has the additional potential effect of increasing demand for new products and opening up new markets.

With respect to previous empirical studies on the issue, our results show that the sectoral perspective emerged as being particularly appropriate since the role of environmental regulation in shaping innovation activities can be better identified by taking the specific characteristics and structure of sectors into account.

Finally, from a policy point of view, the obtained results suggest that governments must consider how to support technological capabilities as well as creating new markets for environmental technologies even through regulatory interventions. In this respect, strong complementarities seem to exist between technology policy instruments and environmental policies, and specific efforts have therefore to be placed to strengthen policy coherence at system level. This is indeed an issue that should be further addressed by the economic literature and adequately taken into account by policymakers.

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