Impact of environmental regulations on innovation and performance in the UK industrial sector

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Abstract

Purpose – The role of environmental regulations in inducing innovation and improving performance has been studied in the literature. However, there have been no studies in the UK using statistical data. This paper aims to study the links among regulations, innovation and performance in the UK using sector level data.

Design/methodology/approach – The paper used structural equation modelling to study the links among the three variables simultaneously.

Findings – The analysis indicates that environmental regulations in the UK are significant in improving economic performance of the industrial sectors. They also find that, in the short run, environmental regulations negatively influence innovation, and innovation negatively influences economic performance in these sectors.

Practical implications – The results have implications both for policy makers and firms in the UK industrial sector. For policy makers, environmental regulations have generally improved economic performance. For firms, the study shows that sufficient planning in meeting government's environment standards can help improve their economic performance.

Originality/value – This is the first study in the UK to explore simultaneously the links among the three variables: environmental regulations, innovation, and performance, using secondary sector level data.

Keywords Environmental regulations, Innovation, Economic performance

Paper type Research paper

Introduction

It is widely accepted that economic growth and development bring not only prosperity but also environmental degradation to nations, especially when adequate measures to minimise the negative impacts are not implemented. Hence, governments formulate environmental regulations to directly or indirectly establish limits on emissions and to control the material and energy outputs of society to the environment (Cohen, 1987;

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Sanchez and McKinley, 1998). Recent examples include the Waste Electrical and Electronic Equipment (WEEE) Directive, the End of Life Vehicle (ELV) Directive and the Restriction of Hazardous Substances (RoHS) Directive. Most of the environmental regulations directed at the industrial sector have had direct impact on the operations and performance of firms in the sector. In some cases, firms have simply reacted to these regulations while there are also several firms that have taken a more proactive role to integrate the need for reducing pollution in their production processes. While firms in the former case might have experienced a negative influence of regulation on their economic performance, firms in the latter case have set examples of the "win-win" situation (Porter, 1991) to show that it is possible to adhere to regulation while at the same time improve economic performance.

The environmentally proactive firms have met the demands of environmental regulation generally by introducing innovations in their products, production and managerial processes. Examples of some proactive innovations include the "design for disassembly initiative" of BMW (Hart, 1995), 3M company's Pollution Prevention Pays principle, Chevron's Save Money and Reduce Toxics (SMART) program (Shrivastava and Hart, 2000), and voluntary participation in ISO 14000 programs. Rugman and Verbeke (2000) discuss the proactive strategic response of six leading international companies, namely Du Pont, Laidlaw, Allied Signal, Honeywell, McDonald's and Xerox.

This literature on the impact of environmental regulation on firm performance is relatively recent but has been extensively studied (e.g. Rugman and Verbeke, 1998, 2000; Sanchez and McKinley, 1998). The resource-based view (RBV) of firms (e.g. Rugman and Verbeke, 1998) and the stakeholder theory (e.g. Orlitzky *et al.*, 2003) have been extensively applied to understand the response of firms to environmental regulations. Given the intensity of environmental regulation, some researchers have argued that regulation be included in the famous "five forces" model of strategy (Porter, 1980) to extend it to a six forces model (Rugman and Verbeke, 2000).

In many cases, innovation plays an intermediary role on the impact of environmental regulations on economic performance. As shown by the examples above, most of the proactive companies that met regulatory requirements improved their economic performance mainly by developing innovative products/processes. The impact of regulations on inducing or suppressing innovations (that may or may not include environmental innovations) in firms has been independently studied heavily in the literature. Some researchers have argued that regulations suppress innovation in firms because the deterministic nature of regulation limits their strategic choices and does not leave enough scope for firms to innovate (e.g. Breyer, 1982). On the other hand, there is also a view that environmental regulations can induce innovation, usually in the longer run, because firms can find innovative ways of not only meeting the regulation but also use the innovation for improving their performance (Porter, 1991).

The research study we report in this paper is part of the ERIPS project (titled "Investigating the impact of environmental regulations on innovation, performance and sustainability in UK manufacturing sector") undertaken in Nottingham, UK, to analyse the responses of the industrial sector in the UK in meeting the challenges posed by environmental regulations. The fundamental assumption being investigated is that environmental regulation affects innovation, business performance and sustainability of manufacturing firms. By doing this, we test the "win-win" argument of Porter (1991) in the UK context using sector level data on industrial performance publicly available from UK government statistics. We use structural equation modelling to test these three relationships simultaneously.

Literature review

The focus of this paper is on the link among three constructs: environmental regulations, innovation and performance. There is some evidence in the literature that environmental issues and the associated innovation tend to affect firm performance positively. However, many studies generally consider only two of the three constructs. Here we consider the literature for each relationship in turn: first, the link between environmental regulations and financial performance. We then look at the relationship between environmental regulations and innovation, followed by the relationship between innovation and financial performance. Finally, we investigate studies that look at the relationship of all three of these constructs simultaneously.

Environmental regulations and economic performance

As mentioned earlier, the management guru Porter (1991) has argued that environmental regulations can positively influence performance defying the traditional view that environmental regulations are harmful to the economic competitiveness. According to the traditional view, although environmental regulations may be necessary and desirable from a social perspective, they force polluting firms to internalise costs that they would not have previously considered. This rise in costs is then reflected in a worsening of financial performance. Furthermore, it leads to a decrease in the international competitiveness of a firm or industry when compared with those from other countries where regulations are not very stringent.

The contrary suggestion of Porter (1991) is that environmental regulations, if properly designed to "aim at outcomes and not methods", can encourage dynamic change and greater efficiency in the use of resources. The dynamic benefits from such practice will more than offset the static compliance costs which have traditionally concerned economists and managers. The resulting possibility is a "win-win" scenario – higher environmental standards mean greater protection for the environment, and will also encourage innovative practices that reduce costs and lead to new products, making firms more internationally competitive. Porter's analysis is informed by anecdotal evidence on the performance of companies in countries with different standards of environmental regulation. In recent years, more formal theoretical formulations of the Porter hypothesis have been devised (Ambec and Barla, 2002; Indrani and Das, 2006).

Whilst further anecdotal and case-study evidence has been given in support of and against the idea of a positive relationship between the stringency of environmental regulations and financial performance (Porter and van der Linde, 1995a; Palmer *et al.*, 1995; Rugman and Verbeke, 2000), it is the statistical analysis that is most interesting. The results of several studies in the literature have found such a positive relationship between environmental management and improved performance (Boiral, 2007; Sarkis, 2001; Hamilton, 1995), thereby supporting Porter's hypothesis.

Klassen and McLaughlin (1996) have tested the linkage of environmental management to firm performance using financial event methodology. They have used news articles from databases to identify significant environmental events/awards to firms and also collected details on environmental performance and financial performance for US firms. They have generally found positive links between environmental management and firm performance. First-time award announcements were associated with greater increases in market valuation, and the increases were small for firms in environmentally dirty industries.

Zhu *et al.* (2007) have studied operations strategies (in the form of green supply chain practices) and performance of Chinese manufacturers in response to environmental and institutional pressures using a survey and statistical analysis. They have found an increased environmental pressure on Chinese manufacturers and importantly that the existence of regulatory pressures improved performance of firms.

Berman and Bui (2001) have found that stricter regulations in the US petroleum refining industry tend to increase abatement costs, but also increase productivity. In the UK context, Salama (2005) has found strong positive relationships between corporate financial performance and corporate environmental performance for top performing companies in Britain.

In general, environmental regulations require significant level of increased capital requirements into pollution-intensive industries. Using regression analysis of data from the US, Dean and Brown (1995) have found that environmental regulations (measured in terms of the ratio of capital expenditure on pollutant abatement to total capital expenditure) discourage entry of new firms (captured in terms of new legally independent firms) in several industrial sectors, and thereby indirectly provide an advantage to incumbent firms.

While many studies measured performance in terms of financial indicators, there are studies that used other indicators such as productivity, efficiency, stock market indices or other similar data. For example, Chintrakarn (2008) has used multiple regression analysis to show that increased stringency in environmental regulations has led to greater technical efficiency (computed using stochastic a frontier model) in US manufacturing industries. Murty and Kumar (2003) have studied the impact of environmental regulation on the performance of firms in Indian sugar industry. They have measured the performance of firms using DEA efficiency scores. They have found that DEA efficiency of firms increased with the degree of compliance of firms to the environmental regulation thereby supporting the Porter hypothesis. Gray and Shadbegian (2003) have used productivity to measure performance but find negative relationships.

Bansal and Clelland (2004) have used regression analysis to study the influence of corporate environmental legitimacy on risk. Using relevant stock market data from highly polluting firms in the US, they have found that firms with higher corporate environmental legitimacy have experienced lower unsystematic risk.

Whilst not strictly testing the impact of regulation on financial performance, a lot of studies have investigated the impact of environmental management practices on performance. Insofar as these practices are inspired by the need to comply with environmental regulation, these studies can be considered an effective test of the Porter hypothesis.

Klassen and Whybark (1999) have developed the concept of the environmental technology portfolio, which is made up of pollution prevention technologies (which prevent pollution from being produced in the first place) and pollution control technologies (which abate pollution once it has been created. They have studied the influence of the proportions of these technologies on manufacturing performance and environmental performance of firms in the USA. They have found that a plant's environmental technology portfolio toward pollution prevention technologies was significantly related to the reduction of hazardous pollutants. They have also found that pollution control technologies contributed little to overall performance. The link between cost reduction and managerial perceptions of best environmental practice has been studied by Christmann (2000), who has found that existing asset base (complimentary assets) play a moderating role in the link.

Orlitzky *et al.* (2003) have conducted an interesting meta analysis to identify the links between corporate social performance and financial performance. They have used data from 52 previously published studies to obtain generalisable conclusions on the links. They have found a general support for positive links. They have further found stronger positive links when the financial performance is measured using accounting based measures than with market indicators.

In contrast with these studies that support a positive relationship, there are also studies that reported a negative relationship between environmental regulations and performance. Filbeck and Gorman (2004) have looked at 24 US electrical utilities firms and find that regulatory compliance tends to lead to lower financial returns. Gray and Shadbegian (2003) have found that greater abatement efforts tend to reduce productivity. Triebswetter and Hitchens (2005) have reported a study conducted in the German manufacturing industry. They have found evidence for their hypothesis that the proportional cost of environmental compliance relative to turnover incurred by the firms is likely to be a negative function of the productivity level. Telle and Larsson (2007) have found that although some studies reported a negative or statistically insignificant relationship between regulatory stringency and traditional productivity growth, when this productivity growth is expanded to include the impact on pollution, the relationship generally became positive.

Thus, a majority of evidence seems to conclude that, for most measures of performance, environmental regulation does in fact have a positive impact as suggested by Porter (1991). It should be noted that the evidence is not 100 per cent conclusive, as shown by Klassen and Whybark (1999), Klassen and McLaughlin (1996), Filbeck and Gorman (2004) and others. As Porter himself recognised, poorly designed environmental regulation may indeed not have a positive effect, just as a begrudging response to regulation by firms may likewise result in the expected negative effect. However, the hypothesis in its most basic form, although fairly radical when first introduced, is now commonly accepted in the policymaking circles of many developed countries, and explicitly forms the basis of environmental policy in the UK (*UK POST*, 2004).

Environmental regulations and innovation

Much of the theory behind the relationship between environmental regulations and innovation also stems from this initial hypothesis of Porter (1991) and his follow-up research (Porter and van der Linde, 1995a, b). It was argued that properly designed environmental regulations, coupled with a proactive attitude of managers to environmental management, would yield innovation that allowed the regulations to be met. The hypothesised innovation would mean the redesign of products and production processes so as to remove waste and pollution from being produced in the first place. Now, rather than having to spend money clearing up this waste, money is saved because the materials that go into the production of this waste are no longer required. The benefit of the environmental regulations is that they prompt firms to look for these ways of "lean manufacturing", whereas these firms may have not done so otherwise. As Palmer *et al.* (1995) have pointed out however, for regulations to inspire innovation in this way managers are required to systematically overlook opportunities for increasing profits. Whilst this conflicts with the neoclassical economic model of how firms operate, the nature of innovation is such that it cannot be seen until after it has come about.

There have also been many studies performed in this area. These can be loosely separated into two groups: those investigating the impact of regulations of environmental innovation in particular and those investigating the impact of regulations on general innovation (*Oslo Manual*, 1992) (that may or may not include environmental innovation). Environmental innovation refers to innovation that tackles environmental issues and includes products/processes that improve energy efficiency, reduce waste or other pollutants, and so on.

Studies of the impact of environmental regulation on environmental innovation in particular yield more conclusive evidence of positive impacts. For example, Pickman (1998) has investigated the impact of environmental regulation on environmental innovation using data on 12 US manufacturing industries over a 20 year time period. She has found a statistically significant positive relationship between both contemporary and lagged environmental regulation on environmental innovation; a relationship that becomes stronger and more significant when the analysis is improved to counter consistency problems. Brunnermeier and Cohen (2003), looking at US manufacturing industries, have found that higher environmental regulation (as measured by pollution abatement expenditure) led to an increase in environmental innovation (as measured by the number of awarded environmental patents), but the effect was very small. Horbach (2008) has investigated the determinants of environmental innovation using firm-level panel data in Germany, and has found that environmental regulation was an important driver. Wagner (2008) has empirically examined the influence of environmental management on innovation of firms in nine European countries using data from European Business Environment Barometer (EBEB) survey. Using multinomial logit/probit models, he has found support for two hypotheses:

(1) A higher level of environmental management systems (EMS) implementation by a firm resulted in a higher propensity of that firm to carry out an environmental process or product innovation.

(2) There was an effect from a firm's adoption of managerial activities not required to form part of a certified EMS in that informing customers, life-cycle assessment, market research on green products, recycling, benchmarking and eco-labelling had an additional positive effect on a firm's propensity to carry out an environmental process or product innovation.

In contrast, studies that consider general innovation seem to yield mixed results. For example, Jaffe and Palmer (1997), who have used panel data on US manufacturing industries, found that there was a small but significant positive effect of environmental regulation on innovation if awarded patents were used as the measure of innovation, but no significant effect if research and development expenditure was used instead. However, Sanchez and McKinley (1998) have studied the moderating roles of organisational characteristics on the relationships between environmental regulation and product innovation in US firms. They have used the ratio of pollution abatement control expenditure (PACE) to the total capital expenditure in different sectors as a proxy for regulatory impact. Using moderated regression analysis, they have found that the relationships between regulatory impact and product innovation were moderated by age (level of customisation) of the plants, with the extent of impact increasing with age (customisation). Regulatory impact had a positive impact on product innovation for older plants and had a negative impact for younger plants. Similarly, regulatory impact had a positive impact on product innovation for plants with higher degrees of customisation of the production process and had a negative impact for plants with lower degrees of customisation.

In general, data on environmental innovations are not easily available but data on general innovation are more readily available via community innovation surveys. These are surveys undertaken across European countries to provide a consistent set of innovation measures both across time and across countries. The Community Innovation Surveys are designed in accordance with the *Oslo Manual*, the OECD document which specifies guidelines by which to collect and interpret innovation data (*Oslo Manual*, 1992). Based on the literature in this section, we see that the effect of environmental regulations on innovation seems to be ambiguous when data on general innovation is used. However, it seems that a relationship between them does in fact exist.

Innovation and financial performance

The link between innovation and financial performance is also an ambiguous one. On the one hand, there is the idea that they are positively related: product innovation can create new markets and can contribute to greater differentiation from the products of rivals, thereby soliciting greater profit margins. As envisaged by Porter and van der Linde (1995a, b) process innovation can reduce costs by increasing energy efficiency and producing less waste. On the other hand, concerted attempts at innovation can be expensive and there is no guarantee that they will yield results that will benefit the company that undertakes them. Even if attempts to innovate (via expenditure on research and development, for example) do result in marketable innovations, the financial benefits of these are unlikely to be realised for some time. Thus, innovation (or, more accurately, attempts to innovate) can represent a potentially large cost in the short run without any guarantee of any benefit to offset this cost in the medium term.

Innovation and performance have been subjects of many research studies in the UK and in several parts of the world, especially in the manufacturing sector. Similar to the links between environmental regulation and innovation, studies on the nature of influence of innovation on performance have also found mixed results – while some studies have found a positive association between innovation and performance, some others have found negative relationships.

One of the earliest studies of innovation and performance has been provided by Karager and Murdick (1966). They have presented in detail the marketing, manufacturing and research aspects of new product development and innovation.

The link between innovation and performance (focusing only on exports) and a comparative evaluation of UK and German manufacturing industries has been discussed by Roper and Love (2002). They have found that innovation and export performance are positively related in both the countries. Dehning *et al.* (2007) have studied the impact of IT based innovative supply chain management in manufacturing firms. They have used essentially secondary data in the context of the USA and have found strong evidence for the positive impacts.

Community Innovations Surveys (CIS) are conducted every four years in several European countries (EIMS, 2003) including the UK and provide the basis for analysis and policy research on innovation. The CIS survey data has been analysed and reported in detail in several research publications (e.g. Cosh *et al.*, 1998; Cosh and Hughes, 2000; Lööf *et al.*, 2003). Lööf *et al.* (2003) have used data from these surveys to compare the extent of influence of innovation on performance in Finland, Norway and Sweden. They have found no significant relationship between innovation and productivity for Finland but the relationship was significant for Norway and Sweden, with a higher value registered for Norway. They have also observed differences in the conclusions based on macro level economic data and micro level CIS data. Cox and Frenz (2002) have studied the relationship between business performance, R&D expenditures and innovation in the UK using firm level data from the second Community Innovation Survey (CIS2). They have obtained data on firm performance (profit margin and the ratio of sales to employees) from the FAME database for a four-year period after the survey. Using logistic regression, they have found that product innovators (including those firms who engage in both product and process innovation) performed better than the non-innovative firms.

However, there are also studies in the literature that found negative relationships between innovation and performance. As mentioned earlier, Lööf *et al.* (2003) have found no significant relationship between innovation and productivity for Finland. Recently, Chang and Robin (2008) have studied the links among public policy, innovation and performance in 23 sectors of Taiwan's manufacturing industry. Performance was measured in terms of total factor productivity by estimating translog production functions. They have found that in general Taiwan firms that spend on innovation tend to perform less well, indicating negative relationships.

Thus we see that the evidence on the nature of relationship between innovation and financial performance is mixed, although it seems that a relationship does in fact exist.

Environmental regulation, innovation and performance nexus

We now focus on some studies that attempted to analyse all the three constructs together. There are only a few studies that attempted to integrate all the three in their analysis.

Triebswetter and Wackerbauer (2008) have studied the impact of integrated environmental product innovation on company competitiveness using qualitative analysis of case studies in selected firms in Munich in Germany. The main hypothesis was that environmental regulation can trigger environmental innovation and possibly lead to a win-win potential for firms, i.e. an improvement of the environment and a better competitive position in the market by partially or more than fully offsetting the cost of regulatory compliance ("strong" version of the Porter hypothesis). Their analysis have shown that environmental regulations of waste water, packaging waste and clean air have not resulted in an improvement in the economic performance in the German manufacturing industry but at the same time have not damaged the economic performance.

Montabon *et al.* (2007) have used corporate environmental reports as the basis for a canonical correlation analysis to assess the impact of environmental practices of indicators of innovation and financial performance. They have employed content analysis of websites of 45 leading companies. They have found that environmental performance has a positive relationship with innovation but negative relationship with financial performance.

Eiadat *et al.* (2008) have analysed the mediating role of environmental innovation strategy on the competitiveness of firms in Jordan using a survey. They have hypothesised that:

- there is a positive relationship between environmental innovation strategy and firms' business performance;
- there is a positive relationship between government environmental regulation and the adoption of environmental innovation strategy;
- there is a positive relationship between managerial environmental concerns and the adoption of an environmental innovation strategy;
- there is a positive relationship between managerial perceptions of importance of stakeholder pressures and the adoption of an environmental innovation strategy; and
- environmental innovation strategy mediates the relationships between salient environmental pressure forces (governmental environmental regulation, managerial environmental concerns, and perceived importance of stakeholder pressures) and firm's business performance.

Using structural equation modelling, they have found evidence for their hypotheses.

Overall, we have identified a system of three hypothesised relationships, and reviewed the empirical evidence for each of them. Using these relationships, we develop our conceptual framework in the next section.

Conceptual framework and hypothesis development

Our conceptual framework is shown in Figure 1. Environmental regulations are thought to improve performance, a hypothesis for which there seems to be considerable evidence, based on a number of different measures of performance. These regulations

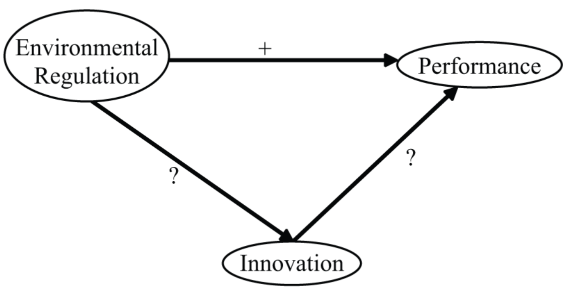


Figure 1.
Conceptual framework showing the influence of environmental regulations and innovation on performance

are also thought to impact upon the levels of innovation in an industry. Previous evidence is not as decisive in saying whether this relationship is positive or negative. Finally, there is the hypothesised relationship between innovation and financial performance. Once again, the existing theory evidence, when viewed as a whole, seems to be inconclusive on whether this relationship is positive or negative.

Based on the literature review and the conceptual framework, we develop the following hypotheses:

H1. The extent of environmental regulations influences economic performance positively (Porter's hypothesis).

H2. The extent of environmental regulations influences innovation performance.

H3. Innovation performance influences economic performance.

We test these hypotheses in the case of the UK industrial sector over the period 2000-2006. We believe that our study makes two contributions to the literature. While a majority of previous studies focussed on these interrelated hypotheses in isolation, ours looks at them simultaneously. In addition, we use available secondary data in the UK to test these hypotheses.

Our methodology for testing these hypotheses is outlined in the next section.

Data and methodology

To test the hypotheses, we use secondary data from the UK industrial sector and analyse using structural equation modelling. This section reviews the data used for our analysis and the methodology. First, we discuss the data used in our analysis and its sources. The next subsection briefly discussed our analysis methodology, namely structural equation modelling.

Data collection

We have collected the required data from the Office for National Statistics (ONS) of the UK Government. We measured the impact of environmental regulations in terms of the statistics on pollution control expenditure available from UK Environmental Protection Expenditure by Industry Survey for the years 2002-2006 (www.defra.gov.uk) (DEFRA, 2008). We obtained data on innovation in these industrial divisions from the UK Innovation Survey. Gross value added (GVA) (at constant prices) in these industrial divisions has been used as a measure of economic performance. These data sources are explained in more detail in the next few subsections.

A governmental regulation is applicable to all the firms in a particular sector but the influence of regulations will differ from sector to sector – more polluting sectors will face higher level of regulation. The question of how environmental regulations affected performance of firms in highly polluting and lowly polluting sectors is of much policy interest. Hence, we focus on sector level in this study. The sector-level data is publicly available from the Office for National Statistics. We have also corroborated our results using firm level micro data available with the Office for National Statistics. We outline our experiences with firm-level data later in this section.

The industrial sectors specified in terms of Standard Industrial Classification (SIC) codes 10-41 are included in the study (see Table I). A total of 16 sectors were considered and data were collected for five years (2002-2006) totalling to 80 data points.

SIC code	Description
14	Mining and quarrying
15-16	Manufacture of food, beverages and tobacco products
17	Textiles
19	Leather products
20	Manufacture of timber and wood products
21	Pulp and paper
23	Manufacture of coke, petroleum and nuclear fuel
24	Chemicals and chemical products
25	Rubber and plastics
26	Manufacture of non-metallic mineral products
27	Manufacture of basic metals
29	Machinery
31	Electrical apparatus
34	Motor vehicles
36	Furniture
40-41	Energy, gas and water

Table I.
Sectors considered in this study

The environmental protection expenditure survey. The UK Environmental Protection Expenditure by Industry Survey 2006 was a survey based on a stratified random sample of 7,850 companies belonging to various industrial sectors with 20.4 per cent response rate (DEFRA, 2008). The survey found that gross spending on environmental protection in 2006 by UK industry amounted to an estimated £4.2 billion, and that operating expenditure accounted for 71 per cent of the total environmental protection expenditure. The primary spending sectors as per the survey were electricity and gas (37 per cent of total spend), food, beverages and tobacco products (12 per cent of total spend) and basic metals and metal products (8 per cent of total spend). The survey also found that the use of environmental management systems was more widespread in the larger companies.

In our study, we use two measures of pollution control expenditure. Operating expenditure (OPEX) covers in-house expenditure associated with the operation of pollution control abatement equipment and payments to external organisations for environmental services, including, labour costs, leasing payments, maintenance costs for equipment and the treatment and disposal of waste. Capital expenditure (CAPEX) covers expenditure on end-of-pipe pollution control equipment and on integrated processes – new or modified production facilities that have been designed so that environmental protection is an integrated part of the process.

The UK Innovation Survey. The UK Innovation Survey (www.berr.gov.uk) is a part of the Community Innovation Survey (CIS) conducted by EU member states that allows the monitoring of Europe's progress in the area of innovation. The survey was originally conducted every four years, but since 2005, it is conducted every two years. For the UK Innovation Survey 2007, questionnaires were sent to 28,000 UK enterprises with ten or more employees and achieved a 53 per cent response rate. It provides the UK data covering the three-year period from 2004 to 2006 (CIS, 2008).

In the UK Innovation Survey, innovation activity was measured using several measures including the following: introduction of a new or significantly improved product (goods or service) (product innovation) or process engagement in innovation projects not yet complete or abandoned (process innovation), and expenditure in areas such as internal research and development, training, acquisition of external knowledge, or machinery and equipment linked to innovation activities (innovation expenditure) (Robson and Haigh, 2008). These measures are expressed in percentages, e.g. the percentage of firms that reported product innovation in a sector. Overall, 64 per cent of enterprises were classified as being innovation-active in the survey. In total, 22 per cent of enterprises had introduced new or significantly improved goods or services in the sample period and 12 per cent had introduced a new or improved process for production or delivery. The share with product (goods and services) and process innovation was considerably greater in larger enterprises (with 250 or more employees).

In our study, we use three measures of innovation: percentage of firms that reported product innovations (PDINNO), percentage of firms that reported process innovations (PRINNO) and percentage of firms that reported spending on innovation related expenditure (INNOEXP).

In addition to environmental regulation and innovation, we measure economic performance of the industrial sectors in terms of gross value added (GVA) (at constant prices) available at the Office for National Statistics. In order to facilitate comparison across industrial sectors, data on pollution control expenditure and GVA have been divided by the number of employees for further use in this study. These three indicators are expressed in thousands of UK pounds per employee. Since data on innovation is expressed in terms of percentages, no attempt was made to adjust the innovation data using number of employees.

Table II gives some descriptive statistics and correlations among the indicators used in this study. The mean operating expenditure during the period was £1,440 per employee, capital expenditure was £560 per employee and gross value added was £98,350 per employee in these sectors over the five years under study. On an average, about 31 per cent of firms reported making product innovation, 21 per cent reported process innovations, while the proportion of enterprises having spent money in some

	Environmental regulation			Innovation		
	OPEX £'000 per employee	CAPEX £'000 per employee	GVA £'000 per employee	PRINNO %	PDINNO %	INNOEXP %
Units						
Mean	1.44	0.56	98.35	31.27	21.20	64.04
Std. Deviation	1.42	1.13	95.72	8.25	3.49	8.44
Correlations						
OPEX	1					
CAPEX	0.592**	1				
GVA	0.422**	0.274*	1			
PRINNO	−0.321**	−0.295**	−0.468**	1		
PDINNO	−0.169	−0.203	−0.457**	0.804**	1	
INNOEXP	−0.275*	−0.285*	−0.579**	0.898**	0.879**	1

Notes: *Correlation is significant at the 0.05 level two-tailed; **Correlation is significant at the 0.01 level two-tailed

Table II.
Descriptive statistics and correlations

innovation-related activity was 64 per cent. It is important to note that pollution expenditures (OPEX and CAPEX) and GVA are negatively correlated with all the three innovation variables. Many of the indicators had significant correlations with each other.

Structural equation modelling

Structural equation modelling (SEM) is a multivariate statistical analysis methodology developed to examine a series of dependence relationships simultaneously, and is particularly useful in testing theories involving multiple and simultaneous inter-dependence relationships (Anderson and Gerbing, 1988; Hair *et al.*, 2006). It is generally an extension of multivariate regression analysis and path analysis. In a SEM analysis, variables that are of interest in a hypothesis but cannot be directly observed are called latent variables. These latent variables are observed in terms of observable or measurable variables, usually called measured variables or indicators. For example, the extent of environmental regulation is not generally observable and could be classified as a latent variable. One way of measuring the extent of environmental regulation is through the amount of spending by companies in pollution control and abatement. Thus pollution control expenditures are its measured variables or indicators. Usually, the latent variables are enclosed in circles while indicators are enclosed in rectangles when the relationships are depicted in a figure. The rectangles and circles are connected using arrows, which represent the dependence relationships.

Figure 2 provides an explanation of the latent variables and corresponding indicators used in this study. Environmental regulation, innovation and performance are the latent variables. As mentioned earlier, the extent of environmental regulation is measured through the amount of spending by companies in pollution control and abatement using two indicators: operating expenditure (OPEX) and capital expenditure (CAPEX). Similarly, the level of innovation is a latent variable. It is measured through three indicators: product innovations (PDINNO), process innovations (PRINNO) and innovation related expenditure (INNOEXP). Economic performance of the industrial sectors is measured using gross value added (GVA).

In SEM, the dependence relationships are captured in a way similar to the approach used in multivariate regression analysis. The latent variables are extracted from the indicator variables using factor analysis. While SEM has been used by researchers for

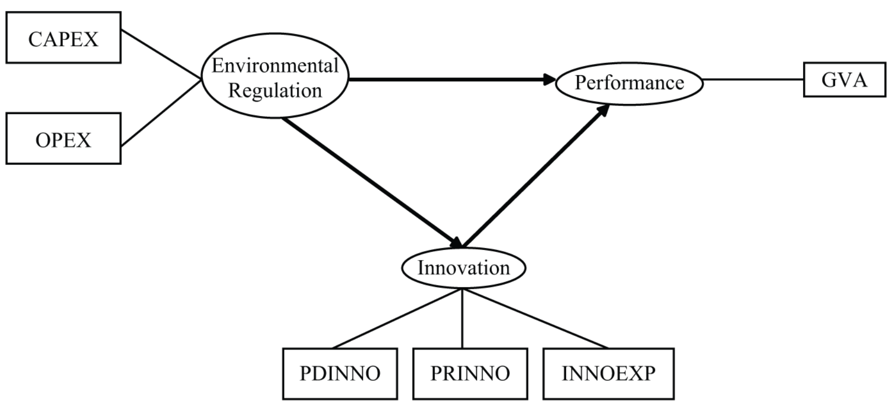


Figure 2. SEM model showing latent and indicator variables

a long time, it has started to receive the attention of empirical Operations Management researchers only recently (Shah and Goldstein, 2006).

Analysis and results

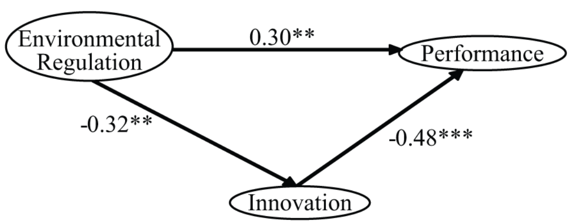
In this section, we describe the use of structural equation modelling to test the three hypotheses identified earlier. We first used a confirmatory factor analysis to verify whether OPEX and CAPEX converge to a single factor that represented environmental regulation, and also to check the three indicators of innovation converged to a single factor.

We performed structural equation modelling (SEM) using AMOS 7. Results are presented in Figure 3. The fit statistics for the model are Chi-square = 12.175 with 8 degrees of freedom (ratio 1.52 and probability 0.144), CFI = 0.987, GFI = 0.953 and RMSEA = 0.08. The ratio of Chi-square to degrees of freedom is within the recommended upper limit of 3, CFI and GFI are well above the acceptable minimum limit of 0.9 and in fact above the minimum 0.95 for a good fit, while RMSEA is at the recommended acceptable limit of 0.08 (Hair *et al.*, 2006). Thus the model indicates a good fit. The standardized regression coefficients that indicate the extent of influence are shown on the arrows. The structural equation model indicates that the extent of environmental regulation in the UK has a positive and significant impact on performance ($\beta = 0.30$, $p = 0.028$), while affecting innovation negatively ($\beta = -0.32$, $p = 0.028$). Innovation influences performance significantly but negatively ($\beta = -0.48, p < 0.01$).

Our analysis indicates that the extent of environmental regulations positively affects economic performance thereby supporting *H1*. *H2* is also supported because our study found that environmental regulations significantly affect innovation performance but the direction of influence is negative. Finally, *H3* is also supported because innovation performance is found to be significant in affecting performance. The influence of innovation performance on economic performance was negative. More details of these results are discussed in the next section. However, before discussing these results further, we present additional analyses to verify the robustness of the above results. These include conducting a similar SEM study with lagged innovation data, and conducting analysis from a detailed firm-level dataset.

Including lagged innovation variables in the SEM analysis

Our SEM results presented above have shown that innovation is negatively related to environmental regulations and also to performance of firms. This may be true in the short-run since generally organisations have a fixed budget and when more money is spent on meeting the requirements of environmental regulations, less money is



Note: ** $p < 0.05$; *** $p < 0.01$

Figure 3. Results of structural equation modelling

available for innovation. It is generally argued that innovation efforts do not bring immediate benefits to organisations but will bring benefits a few years down the line (Pickman, 1998). Hence, we have used lagged innovation variables (with one year lag) in our structural equation model. This has reduced our effective sample size from 80 to 64. Results are shown in Figure 4. Surprisingly, the SEM results are quite similar to the results shown without lagged innovation variables with equally good fit statistics. The fit statistics for the model are Chi-square = 6.335 with 8 degrees of freedom (ratio 0.79 and probability 0.61), CFI = 1.00, GFI = 0.969 and RMSEA = 0.00.

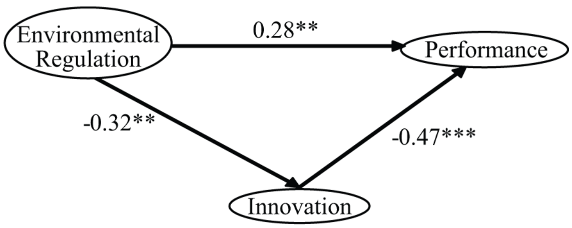
Our experiences with using firm level micro data

We have tried to collect firm level micro data to carry out more detailed analysis. Such a micro level data are not publicly available but can be accessed with permission at the virtual micro-data laboratory (VML) facility of the Office for National Statistics. We did attempt to analyse using firm level data. However, we experienced several limitations both with the data and with the analyses.

Unfortunately, detailed firm level data on pollution control expenditure was not available at the VML facility. After detailed searches, we found that pollution control data was available only for the year 1994 in Annual Respondents Database (ARD) and not for any other years. Data on community innovation surveys was available from 1994 onwards. Data on performance was available for a number of years.

In addition, the VML facility did not have access to software for structural equation modelling. Hence, we had to restrict our analysis only to 1994 data and to simple regression analysis using SPSS. However, we did find similar results when this data is used.

We have used data on pollution control expenditure by firms as a proxy for the intensity of environmental regulations, number of patents (1994-1996) as the proxy for innovation, and gross value added at factor prices as a measure of performance. We performed a simple regression analysis with gross value added as the dependent variable, pollution control expenditure and number of patents are used as the independent variables and number of employees as the control variable. Results are presented in Table III. Results reported in Table III are based on statistical data from ONS which is Crown copyright and reproduced with the permission of the controller of HMSO and Queen's Printer for Scotland. The use of the ONS statistical data leading to the results reported in Table III does not imply the endorsement of the ONS in relation to the interpretation or analysis of the statistical data. This work uses research datasets which may not exactly reproduce National Statistics aggregates. Copyright of the statistical results may not be assigned, and publishers of these data must have or



Note: ** $p < 0.05$; *** $p < 0.01$

Figure 4. Results of structural equation modelling when innovation variables are lagged by one year

Table III.
Results of regression analysis using detailed firm level data at the VML of the Office for National Statistics, UK

Dependent variable: gross value added at factor costs	Standardised coefficients
Control variable: total employment	0.91*
Independent variables:	
Pollution abatement expenditure	0.062*
Number of patents the enterprise applied for 1994-1996	–0.093*
Regression fit statistics:	
R^2	0.839
R^2 adjusted	0.838
F statistic	1659*
Sample size	962

Note: $^{*}p < 0.001$
Source: Office for National Statistics, UK

obtain a licence from HMSO. The ONS data in these results are covered by the terms of the standard HMSO "click-use" licence. We have verified and found that all assumptions for regression are satisfied. We have tested for normality assumption of the error terms, checked for the presence of outliers in the data and checked for multi-collinearity and heteroskedasticity. The fit statistics for the regression, shown by high R^2 and significant F-statistic, are good. Both the independent variables are very highly significant. The results show that pollution control expenditure is positively related to firm performance while number of patents is negatively related. Thus, our findings from SEM are validated with the help of detailed firm-level data.

Discussion

We believe that our findings have implications for policy makers involved in formulating environmental regulations. Our findings are also consistent with the results reported in the literature in various country contexts. We discuss these implications in this section.

The most important result of our study is the significant positive influence of environmental regulations on economic performance. This result supports Porter's hypothesis. By supporting this hypothesis, our study joins a series of high profile studies that found similar evidence in different country contexts (Boiral, 2007; Sarkis, 2001; Cole *et al.*, 2005; Hamilton, 1995; Christmann, 2000; Klassen and McLaughlin, 1996; Klassen and Whybark, 1999; Zhu *et al.*, 2007; Lopez-Gamero *et al.*, 2009). This result shows that industrial sectors in which firms have invested in pollution control expenditure for meeting environmental legislations are also recording better economic performance. This result is consistent with those of Klassen and McLaughlin (1996) and Porter (1991) who argued that firms that tend to be proactive in meeting regulations will be able to both meet the legal requirements and also improve performance.

Our study has found that investments in pollution control expenditure tend to negatively influence innovation in the industrial sectors considered. It is important to note here that this negative influence occurs in the short term. This could be because firms that spent more on pollution control expenditure did not spend much on innovation in the short run. Our finding generally agrees with that of Sanchez and McKinley (1998) who found such a negative relationships for older plants. However, this finding is somewhat contrary to that of Wagner (2008) who generally found a positive relationship. Finally, our study has found that the sectors registering higher percentages of process innovation, product innovation or sectors in which larger percentage of firms invested in innovation, have generally performed less well in terms of economic performance. This finding is consistent with some other previous studies (e.g. Chang and Robin, 2008, for Taiwan; and Triebswetter and Hitchens, 2005, for Germany) as well.

What are the implications of these findings? Three main implications for managers can be inferred. First, our findings reiterate the Porter's win-win proposition and provide evidence that environmental regulations initiated by government provide financial benefits to organizations. Thus, organizations should institutionalize environmental considerations as a part of their long-term strategic initiatives. Second, although 64 per cent of the firms in our sample have invested in innovation (both product and process related), such drive in innovation is not on the basis of active environmental considerations. As environmental initiatives have a positive impact on firm financials, it is imperative that the innovation initiatives are closely linked with pre-determined environmental targets. Third, as many of the innovation efforts is often based as a response to competition and treated as a way to get short-term economic benefits, its long-term opportunities and the scope to integrate it into environmental initiatives are lost. Thus, environmental compliance when made as a part of strategic decision making process in organizations can have profound inference on both financial performance and innovation activities.

It should be noted that our choice of the use of pollution abatement expenditures (OPEX and CAPEX) to proxy for the severity of environmental regulations suffered by a particular sector in a particular year may have influenced some of the results. While it represents a reasonable measure of regulatory impact and used by previous studies (Sanchez and McKinley, 1998), in actual fact, it is a measure of the expenditure of that sector on pollution abatement equipment. So our results are saying that those sectors which spend more on pollution abatement innovate less. In a way, this is more in accord with Porter and van der Linde (1995a, b) than we first inferred: less innovative firms will respond to the need for improved environmental performance (be it from regulation or other sources) by abating more. Thus they will need to innovate less. Conversely, more innovative firms will meet their environmental obligations by altering their products and their production processes, resulting in less need for expenditure on pollution abatement equipment. Thus our measure of regulation may lead us to biased results. Ideally, other variables would be incorporated into the analysis to represent regulation as well. In addition, data on end-of-pipe control or integrative pollution control processes can be used to identify the impact of proactive pollution control efforts or reactive efforts on performance similar to the studies by Klassen and Whybark (1999).

Conclusions and scope for future research

Our results support all the three hypotheses. We have found evidence that environmental regulations (measured in terms of pollution control expenditure) positively influence performance of industrial sectors considered in this study. We also found that environmental regulations have significant negative influence on innovation in these sectors and that innovation influenced performance significantly but negatively.

The most obvious implication of these results from a policy making perspective is that the regulation in the UK is properly formulated to help firms improve their economic performance in addition to improving the environment. Our study has also found negative relationship between innovation and environmental regulations and between innovation and performance in the short run.

In spite of the relevance of our results, a number of limitations of the study should be mentioned here. First of all, the reliability of our results would have improved by increased sample size. We had to use sector-level data since firm level data were not publicly available, and we could not use SEM in the VML where we could access to firm-level data. Use of sector-level data severely restricted our sample size. Sample size was further restricted by the fact that pollution control expenditure and innovation data compiled by different agencies and are aggregated across different groups of sectors. To increase the sample size, we used the sector-level data for different years (2002-2006). However, if we had sufficient sample size for each year, we could have tested our hypotheses for different years to spot the trend.

More data to represent environmental performance might have been included. Environmental regulations represent only one of many environmental pressures acting on a company. While regulations are pressures imposed by the government, other environmental pressures can be imposed by employees, competitors, supply chain partners and local community. For example, many companies voluntarily get themselves certified as per ISO 14000 standards – partly to improve the green image of the company but also based on pressures by supply chain partners. Indicators representing such additional pressures (e.g. number of ISO 14000 certifications) would have been included in our study.

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