Learning To Change: The Role of Organisational Capabilities in Industry Response to Environmental Regulation

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I hereby certify that this material, which I now submit for assessment on the programme of study leading to the award of PhD, is entirely my own work and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work.

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Contents

Abstract

This thesis looks at the potential for environmental regulation to induce economically beneficial technical change in industrial activity. This question is explored in the context of the recent introduction of Irish legislation aimed at promoting such technical change. The research focuses on the experience of one industrial sector, the pharmaceutical manufacturing sector, in making the adjustment to the new Integrated Pollution Control regulations. The key question of interest is the importance of organisational capabilities in determining firms' ability to adjust to a changed regulatory environment, to develop new organisational processes and to implement technical change.

The thesis presents an analysis of competing theoretical approaches to analysis of regulation and technical change. The evolutionary theory of the firm, with its emphasis on organisational capabilities as the driver of technical change in firms, is identified as the most appropriate framework for the development of a coherent model of the relationship between environmental regulation and firm technical change. The empirical research was undertaken using two, complementary approaches. Measures of capability were constructed for all pharmaceutical firms licensed in the first phase of IPC implementation. This allows for comparative analysis of the role of organisational capabilities in the sector's response to new environmental regulations. Further analysis of questions around the origins, significance and contingent nature of capabilities is explored in qualitative, case study research in five selected case companies.

The research presented in this dissertation show that firms are differentially able to respond to technology-forcing regulations and that these differences are associated with differences in organisational capabilities. Firms with high performing dynamic capability were able to ensure effective environmental performance, preserving flexibility of action and supporting overall competitiveness.

List of Tables and Figures

List of Abbreviations

AER	annual environmental report
BATNEEC	best available techniques not entailing excessive cost
CBA	cost-benefit analysis
EIA	environmental impact assessment
ELV	emission limit value
EMAS	eco-management and audit scheme
EMP	environmental management programme
EMS	environmental management system
EPA	Environmental Protection Agency
FDA	US Federal Drug Administration
FDI	foreign direct investment
GMP	good manufacturing practice
IDA	Industrial Development Authority
IPC	Integrated Pollution Control
IPCMF	Irish Pharmaceutical and Chemical Manufacturers Federation
IPPC	Integrated Pollution Prevention and Control
MAC	maximum allowable concentration
NCE	new chemical entity
NCE	neoclassical economics
NGO	non-governmental organisation
UNEP	United Nations Environment Programme

1: Introduction

This thesis looks at the potential for environmental regulation to induce economically beneficial technical change in industrial activity. This question is explored in the context of the recent introduction of Irish legislation aimed at promoting such technical change. The research focuses on the experience of one industrial sector, the pharmaceutical manufacturing sector, in making the adjustment to the new regulations. The key question of interest is the importance of organisational capabilities in determining firms' ability to adjust to a changed regulatory environment, to develop new organisational processes and to implement technical change.

The thesis begins by presenting an overview of the background to the issue being explored. Chapter two outlines the origins of integrated pollution control (IPC) licensing in Ireland. The history of the environmental legislation of industrial activity in general, and the pharmaceutical sector in particular is presented. An assessment is made of the strategic importance of environmental management issues to this sector.

The identification and development of the theoretical framework is the subject of chapters three, four and five. Chapter three is an exploration of the treatment of technology-forcing environmental regulation in the dominant discipline of neoclassical environmental economics. Theoretical models and empirical studies from within this tradition are examined, showing the consistent position that environmental regulation cannot lead to economic gains within firms. The connections between the discipline's position on technology-forcing environmental regulation, the underlying theory of a profit-maximising firm, and the core assumptions of neoclassical economics are established.

In chapter four a challenge to the orthodoxy made by Porter, who argues that regulation has the potential to encourage potentially beneficial technical change within firms, is examined. Through close examination of the debate between Porter and neoclassical environmental economists, the conflicting theories of the firm underpinning the two sides of the debate are identified. The suitability of Porter's approach as the basis for future research is discussed. Chapter five then identifies evolutionary economics as an approach that has an underlying theory of the firm appropriate to the analysis of the impact of regulation on technical change within firms.

The methods, results and analysis of the research are presented in chapters six, seven, eight and nine. Chapter six identifies the key research hypotheses to be addressed in the thesis: not all firms will be able to respond to the new regulation as the regulators intend; firms will be differentially successful in the take-up of cleaner technology solutions; firms will differ in the extent to which they have successfully introduced the managerial changes required by the regulators; these differences will be associated with the presence or absence of organisational processes for problem solving and strategic development.

Chapter six also clarifies the methodological approach taken on the research of organisational capabilities. The data collection process is explained, and measures of capability are developed. The empirical research was undertaken using two complementary approaches. Measures of capability were constructed for all pharmaceutical firms licensed in the first phase of IPC implementation. This allows for comparative analysis of the role of organisational capabilities in the sector's response to new environmental regulations. The findings of this research are outlined in chapter seven.

Further analysis of questions around the origins, significance and contingent nature of capabilities is explored in qualitative, case study research in five selected case companies, in chapter eight. The hypothesis that dynamic capabilities are central to a firm's ability to adapt to a changed regulatory environment is further explored by examining in detail the organisational processes for problem solving and strategic development. Analysis of the findings is developed in chapter nine, where it can be seen that the synthesis of the two research approaches allows for a full exploration of both the development and the implications of organisational capabilities. The thesis conclusions are summarised in chapter ten.

2: Environmental Legislation and the Pharmaceutical Sector in Ireland

Introduction

This chapter sets the context for the research by providing an outline of the development of Ireland's legislation of the environmental impact of industrial activity. The regulatory instrument that is the subject of this thesis, integrated pollution control licensing, is described in detail. Pharmaceutical manufacture was the first class of industrial activity to be licensed under the new regulations and is the sector selected for study in this thesis. A brief history of the sector is given, concentrating on the impact of environmental management issues. Finally, an assessment is made of the strategic importance of environmental compliance and cleaner technology to the Irish pharmaceutical sector.

The Development of Environmental Legislation

When the European Economic Community (EEC) was formed in 1957 the Treaty of Rome did not make specific provision for the EEC to act in matters of environmental protection. At that time environmental damage was not a significant issue and governments had not foreseen the impact it would make on economic performance and quality of life. In the late 1960s the EEC became aware of the need to legislate to protect the environment and in 1970 the Commission proposed a formal action plan to establish legislation requirements. Legislation was brought in under three articles of the Treaty of Rome:-

Article 100	directs the Commission to provide legislation to achieve the establishment and functioning of the common market.
Article 235	is a catch-all article that provides the Commission with 'open competence' to take measures in areas which the Treaty of Rome has not explicitly provided for.
Article 2	charges the Commission with promoting the harmonious development of economic activity, balanced expansion and an accelerated raising of the standard of living.

The legislative programme introduced by the Commission during the 1970s focused on damage abatement of the most immediate pollution problems. The issue of water pollution was given priority by the Commission and a number of directives were introduced during the 1970s.[1] They established guidelines for monitoring and set maximum allowable concentrations[2] (MAC) for a range of over sixty pollutants.

In Ireland, which had joined the EEC in 1973, the importance of environmental protection had not been recognised in the legislation. The basis of Irish environmental legislation was the Local Government (Planning and Development) Acts, 1963-1976 which provided for the regulation of land and the laying down of conditions of use. These acts were never designed as instruments of environmental policy but evolved in an ad hoc way as the principle mechanisms by which the State regulated environmental damage. Under these acts the local authorities (27 county councils and five city corporations) were responsible, as part of the planning process, for determining the potential impact of new projects. They had the discretion to amend the development plans and to impose emission standards as part of the plant's permission. Local authorities had wide discretion but little in the way of guidance or even formal environmental policy to direct them. A circular from the Department of the Environment advised 'control authorities are expected to operate on the basis that standards should be reasonably practicable having regard to all the circumstances relevant to any particular pollution source'.[3] Standards were set individually for each plant, based on an approximate calculation of the area's assimilative capacity[4] and an estimate of emissions from the information provided by the applicant, and the process was open to bargaining by the firms and the IDA. Once a firm was established there

[1]Directives: 76/160/EEC on bathing water; 75/440/EEC on drinking water; 76/464/EEC on aquatic pollution.
[2] MACs are environmental quality standards that set limits on the allowable concentrations of pollutants in the environment. This means that for a given standard a country with a large natural assimilative capacity can emit and absorb a greater amount of pollution than a less well endowed country.
[3] Circular ENV 22/74, 10.9.1974 quoted in Scannell (1982).
[4] Assimilative capacity is a measure of the extent to which a given natural environment is able to receive and attenuate pollution without suffering long-term or irreversible harm. For example, in a windy country air emissions disperse relatively quickly; this country has a higher assimilative capacity for air pollution than a country without the benefit of strong winds.

was no further review of standards and the local authorities relied on self-monitoring by the plants.

In 1977 the Local Government (Water Pollution) Act was introduced in order to comply with a series of EEC directives on water pollution, and was the first piece of legislation specifically dealing with the environment. It provided for the licensing of discharges to water for new and existing plants. A compliance date was not set for enforcement of the licensing of existing plants and local authorities were thus free to postpone licensing indefinitely; by 1979 only 12 plants had been licensed (Scannell, 1982).

In the 1980s there was growing concern in Europe about the effects of acid rain. The Commission began to tackle air pollution and became more proactive, moving away from MACs and introducing air quality limit values for serious pollutants such as lead, sulphur dioxide, nitrogen oxides and smoke particles.[5] The reduction of air emissions from industrial plants was also legislated for with Directive 84/360/EEC which introduced the requirement for BATNEEC (best available techniques not entailing excessive cost). BATNEEC is a framework concept whereby regulators define the level of environmental control to be employed by firms based on what is technically achievable. Regulators must take account of two sets of economic criteria: (a) the gains in environmental quality achieved weighed against the costs to industry (cost-benefit analysis) and (b) the affordability of these technologies in the sector (Sorrell, 2001). Some member states voiced concern at the impact of this environmental legislation on country competitiveness. The introduction of uniform emissions standards[6] was especially controversial. Countries with low assimilative capacity argued that uniform emission standards were fairer as they did not impact on intra-EC competitive advantage. Other countries, such as the UK and Spain, argued that large assimilative capacity was a natural advantage, like a good climate or soil quality, and as such should not be legislated away.

[5] Directives: 80/779/EEC on sulphur dioxide and smoke; 85/203/EEC on nitrogen dioxide; 82/217/EEC on lead

[6] Uniform emission standards set standards on the emissions (usually expressed as concentrations per unit time) that a facility is permitted to discharge, without reference to the assimilative capacity of the receiving environment, and so affect all countries equally.

In 1987 Ireland implemented these directives and introduced its first effective environmental legislation. The Local Government (Air Pollution) Act represented a radical overhaul of existing legislation. It made provision for compliance with existing EC directives on air pollution, including the Industrial Plant Directive (84/360/EEC) and the directives on limit values for lead, sulphur dioxide, particulate matter and nitrogen oxides. It also introduced the requirement for the BATNEEC standard which requires new plants to use the most efficient and cost-effective equipment and processes that are internationally available. This act has had a significant impact on the Irish pharmaceutical sector, imposing substantial abatement costs. The Federation of Irish Chemical Industries nominated 1988 as the year in which environmental concerns were going to start to affect the way they operated (FICI, 1989).

The Commission introduced a wide range of directives during the 1970s and 1980s. But although environmental legislation was successfully introduced, the three articles of the Treaty of Rome did not provide a very secure or satisfactory underpinning for a complete and far-reaching programme of legislation. The need to achieve unanimity in voting meant that legislation had to be watered down to the lowest acceptable proposal before being agreed upon. An example is the 1970s programme to reduce water pollution; by 1993 25 percent of the Community's water supplies were unsafe for drinking and the necessary legislation was not adequate to obtain prosecutions (Coopers and Lybrand, 1994). As not all countries were equally committed to the need for extensive environmental protection there was always a threat that a country could go to the European Court and challenge the Commission's competence. In 1987 the Single European Act, which provided legislation necessary for the completion of the internal market, amended the Treaty of Rome to include specific provision for a Community environmental policy. As well as this, Article 130 held that 'environmental protection requirements must be integrated into the definition and implementation of other Community policies.' The Treaty on European Union (1993) signalled an increased commitment to protection of the environment and altered the

Commission's objective from 'continued and balanced expansion of the Community' to 'sustainable, non-inflationary growth of the European Community, respecting the environment.' The Treaty provided for the increased involvement of the European Parliament in the legislative process; as the European Parliament is traditionally more progressive than the Council of Ministers on environmental matters this marked a strengthening of EU environmental policy. The Treaty also resolved the ambiguity whereby some legislation, relating to the completion of the internal market (environmental legislation relating to product standards fell into this category), required only majority voting by the Council but other legislation required unanimous voting.

The increased commitment to environmental protection signalled in the Single European Act (1987) and the Treaty of European Union (1993) was reflected in the proactive and innovative legislative programmes proposed by the Commission in the 1990s. The Commission began to implement a more comprehensive approach to environmental protection. The use of emission limit standards is being complemented with the development of legislation that uses the discipline of the market (for example environmental taxes) and consumer power to strike a balance between environmental protection and economic development. In 1989 the polluter pays principle was the impetus for a proposed directive on civil liability for environmental damage.[7] In addition the importance of the precautionary principle was increasingly acknowledged in legislation; the principle states that, given scientific uncertainty (for example, about the effects of toxic emissions on the environment) risks should not be taken but instead the most stringent controls possible with current technology should be adopted.[8] Legislation on voluntary eco-auditing of companies' environmental performance, a voluntary eco-labelling award scheme for environmentally friendly products and the right of freedom of access to environmental information have been introduced[9]; this legislation is aimed at encouraging consumer awareness and increasing benefits to firms of good environmental practice.

[7] OJ 1989 C251.

[8] The precautionary principle is stronger than the BATNEEC standard, as the determination of the best technology possible is made without reference to economic criteria such as availability and affordability.

[9] Regulation (EEC) No. 183/93 on eco-auditing; Regulation No. 880/92 on eco-label award scheme; Directive

The Introduction of Integrated Pollution Control Licensing in Ireland

The 1990s saw a strong commitment to environmental protection in Ireland through the implementation of a progressive programme of environmental legislation. By 1996 a review found that Ireland was one of the most advanced EU countries in terms of environmental directives adopted, with 127 out of a potential 133 directives adopted (Sheerin, 1997).[10] In 1992 the Environmental Protection Agency Act[11] established a national authority to assume the environmental responsibilities previously held by local authorities. The Freedom of Environmental Information Act[12] establishes a legal right to access environmental information. Ireland introduced integrated pollution control licensing of industry[13] while it was still only at the proposal stage at the European Commission.[14] Not only did Ireland anticipate the 1996 EU directive[15] on integrated pollution prevention and control (IPPC) by a number of years, but the Irish legislation is also in some respects (discussed below) more demanding.

IPC licensing represents a move from single media licensing, which licensed emissions to only one receiving medium (air, water or solid waste), to integrated licensing which considers the environmental impact of a plant's entire activity. IPC licensing aims to address two problems experienced with single-media licensing. Firstly it has become apparent that many environmental problems have multi-media causes, and therefore cannot be adequately addressed without an integrated approach. 'The environment functions as an integrated whole and each part is to some degree dependent on the other. Recognition of this inter-relatedness would improve our ability to constrain and reduce pollution' (UK Department of the Environment, 1988, p. 3). Secondly, experience has shown that setting environmental standards for

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90/313/EEC on freedom of environmental information.

[10] Although subsequently the EU Commission has been critical of Ireland's progress in implementing and enforcing directives.

[11] Environmental Protection Agency (Establishment) Order, 1994 (S.I. No. 213 of 1993).

[12] Freedom of Access to Information on the Environment Regulations, 1993 (S.I. No. 133 of 1993)

[13] Environmental Protection Agency (Licensing) Regulations, 1994 (S.I. No. 85 of 1994)

[14] *Proposal for a Council Directive on Integrated Pollution Prevention and Control*. Commission of the European Communities COM (93) 423 (Final).

[15] EU directive 96/61/EC

individual media inevitably leads to standards of differing stringency (Irwin, 1990). This was the case in Ireland where the air standards introduced in 1987 were significantly more stringent than the water standards, which dated back to 1970. These imbalances can mean that licensed facilities have an incentive to transfer pollution to the least protected medium. For example firms have met high air standards by using scrubbers that remove emissions from the air effluent, transferring it to water effluent treatment systems and ultimately discharging water and solid waste (Hersh, 1996).

The integrated approach allows regulators to balance overall environmental priorities. Within a given licence they have an opportunity to make trade-offs between individual environmental impacts in order to optimise the total impact of an activity. For example a particular treatment technology might be effective at removing a pollutant, but be rejected by the regulators on the grounds that the negative environmental impact of the high energy use required would outweigh the abatement benefits. As well as environmental benefits IPC licensing has the potential to improve economic efficiency in achieving effective environmental protection. An integrated regulatory system has the potential to reduce administrative costs for licensed firms. It may also lead to savings in the costs of pollution control, as firms no longer need to respond to fragmented environmental control requirements and can optimise pollution control technology for the whole plant (Irwin, 1990).

In implementing IPC licensing, both Ireland and the EU are expecting to achieve more significant economic advantages than the administrative synergies outlined above. IPC licensing is explicitly being used as a vehicle for encouraging firms to integrate environmental controls into manufacturing (cleaner technologies) in order to prevent (rather than treat) pollution. Cleaner technology is 'approaches to manufacturing that minimise the generation of harmful waste and maximise the efficiency of energy use and material use' (Christie, 1995, p.31). This improved use of costly inputs and avoidance of treatment costs could potentially allow firms to achieve economic advantages such as material savings, process efficiencies, reduced environmental control costs and market advantages (Porter and van der Linde, 1995a).

The EPA has made clear that it expects firms to move away from a focus on end-of-pipe technology. End-of-pipe technology can be defined as 'downstream waste treatment' (Christie, 1995, p.31), projects that are waste based; primarily use equipment; and result in treatment of waste, not reduction or reuse. Cleaner technology includes all approaches that result in the production of less waste either through source reduction, reuse or recycling. The explicit aim of the IPC licensing system is the development in licensed firms of an environmental strategy focused on cleaner technology.

> The old command and control system of environmental protection has been shown to be inadequate. The IPC approach is a more participative one, allowing the company an opportunity to set out programmes for continuing improvement towards desirable standards through the promotion of the use of cleaner technologies rather than end-of-pipe treatment (EPA, 1997, p. 1).

The EPA's goal in determining the licence conditions for a firm is to minimise the total environmental impact of the firm. 'The main environmental objective of IPC is to prevent or solve pollution problems rather than transferring them from one part of the environment to another' (EPA, 1996a, p. 2). Under the previous licensing system, emission limit values (ELVs) were set in the licence conditions and firms were obliged to demonstrate that pollution emissions fell within the limits. The ELVs set by regulators at that time were established with respect to available abatement technology, that is, end-of-pipe waste treatment equipment that ensured waste streams from the production process were treated so as to comply with the permitted levels of emissions. For example, organic wastewater effluent can be biodegraded in a wastewater treatment plant. Air emissions can be stripped out by a scrubber for destruction incineration, on or off site. Technical skills are required for the operation and monitoring of these facilities, but without generally having any impact upon the rest of the plant's operations and typically this function is organised as a discrete environmental unit.

The EPA's explicit preference is that emission standards be met through the use of cleaner technology. Firms are expected to demonstrate a commitment to implementing pollution prevention over waste treatment. 'It should be clearly understood that achieving the emission limit values does not, by itself, meet the overall requirements in relation to IPC. In addition to meeting such values the applicant will be required to demonstrate that waste minimisation is a priority objective...' (EPA, 1996, p. 1). Emission limit values are set by regulators so as to be achievable with currently available technologies. This is the BATNEEC standard:

> BATNEEC means *"the best available technology not entailing excessive costs"*. The technology in question should be **Best** at preventing pollution and **Available** in the sense that it is procurable by the industry concerned. **Technology** itself is taken as the techniques and the use of techniques, including training and maintenance etc. NEEC addresses the balance between environmental benefits and financial expense (EPA, 1996, p.4, emphasis in original).

The EPA issues a guidance note of appropriate technologies which have been used to set the ELVs. Firms are obliged to meet the ELVs, but are not limited to using the technologies defined in the guidance note:

> The BATNEEC identified in the Guidance Note is used as a basis for setting emission limit values... Technologies identified in the BATNEEC guidelines are considered to be current best practice for the purpose of setting emission limit values. These technologies are representative of a wide range of currently employed technologies appropriate to particular circumstance' (EPA, 1996, p. 3)
>
> However, the guidance issued in this note in respect of the use of any technology, technique, or standard does not preclude the use of any other similar technology, technique, or standard which may achieve the same emission... (EPA, 1996, p.3).

Under the current legislation, BATNEEC is now defined with an emphasis on technologies for pollution prevention over treatment. 'In the identification of BATNEEC, emphasis is placed on pollution prevention techniques, including cleaner production technologies and waste minimisation, rather than end-of-pipe treatment' (EPA, 1996, p. 3). 'BATNEEC will be used to prevent, eliminate or, where that is not practicable, limit, abate, or reduce an emission from an activity...' (EPA, 1996, p. 3).

For new facilities the BATNEEC standard is held to be the ELVs set by the guidance note. For existing facilities the requirement to balance environmental benefits and financial expense means that a lower level may be determined to be BATNEEC for that facility. 'The BATNEEC guidelines are not the sole basis on which licences' emission limit values are to be set, since information from other sources will also be considered including site-specific environmental and technical data, plant financial data and other relevant information' (EPA, 1996, p.4).

> For existing facilities, additional regard shall be had to:
> - the nature, extent and effect of the emission concerned;
> - the nature and age of the existing facilities connected with the activity and the period during which the facilities are likely to be used or to continue in operation, and
> - the costs which would be incurred in improving or replacing these existing facilities in relation to the economic situation of activities of the class concerned. (EPA, 1996, p. 4)

In issuing the first round of IPC licences the EPA revised and tightened the water emission levels for most firms; these levels had not been revised since the original water pollution licenses were issued in the 1970s. This tightening was signalled well in advance and many pharmaceutical firms upgraded their water treatment facilities in the early 1990s in anticipation of the tighter legislation in the future. The air emission levels were not tightened; as the legislation was recent, the BATNEEC that had been defined for compliance was still current. Furthermore firms had either just completed or were still engaged in a programme of investment to ensure air standards compliance. In their application for an IPC licence firms were asked to identify whether or not they were in compliance with the BATNEEC standards, and where necessary to provide details of their plans to upgrade to these standards. The EPA has made explicit its intention that *all* facilities should work towards attaining current BATNEEC, notwithstanding the provision of the legislation that it is mandatory only for new facilities. For firms that had not achieved BATNEEC by the time of their IPC licence application the EPA made compliance a condition of the licence, specifying the pre- and post-compliance emission levels and the date for achieving BATNEEC.

The IPC licence places additional requirements on firms that go far beyond meeting emission limit values. Firms are also required to show continuous improvement in environmental performance, and to support this with procedures for environmental planning and management. Condition 2 of the IPC licence sets out the requirement for the licensee to 'establish and maintain an Environmental Management System (EMS) which shall assess all operations and review all practicable options for the use of cleaner technology, cleaner production and the reduction and minimisation of waste...' (EPA, 1997, p. 4). The reason for this condition is 'to make provision for management of the activity on a planned basis having regard to the desirability of ongoing assessment, recording and reporting of matters affecting the environment' (EPA, 1997, p. 5). The EPA is unique among EU regulators in its explicit focus on structures for environmental management. This focus comes from the EPA's belief in the importance of processes for management and information generation for long term continuous improvement; 'the knowledge gained from a thorough understanding of material flows within a facility' (EPA, 1997, p. 17). This is supported by the literature on technical change, which places as much importance on managerial capabilities as on technical capabilities: '... incremental innovation is not of course simply a process of *technical* change, it also involves *organisational* innovation and skill improvements based on experience (Freeman, 1992, p.79, emphasis in original).

Similar emphasis is identified by research on cleaner technology adoption: 'the common element is not technical but managerial – cleaner production is essentially a way of thinking about the energy and materials costs of a product and the impacts along the product's entire value chain' (Christie, 1995, p. 34). Echoing the literature on technical change, Christie describes the introduction of cleaner technology as having wider requirements than simple technology adoption by a specialist, requiring management of information and skills to ensure effective integration with an overall environmental strategy, analysis of alternatives and impact and measurement of results. Although the technical change required may not be radical, the move to cleaner technology does require new forms of measurement, new perceptions on the behalf of management, and new organisational routines.

Looking at the EPA's guidance note (1997) it is possible to identify the key elements that the Agency expects to see in an environmental management system: measurable objectives and targets; management procedures and documentation; demonstrable continuous improvement.

> 3.2 Schedule of Objectives and Targets
>
> 3.2.1 Purpose
>
> The purpose of this requirement is to ensure that there are clear environmental goals within an organisation as a whole. Goals should be set to achieve a year-on-year improvement but not necessarily in every area of the activity, i.e. they are strategic and not short term.
>
> Targets should be demanding, in that they should require a special effort to achieve them. There is little point in setting targets at a low level as they provide little motivation or satisfaction upon achievement. In any case low level targets are unlikely to be approved by the Agency and may result in licence Inspector establishing targets for the specified project. Objectives and Targets should be quantified where ever this is practical to ensure that real attainment is recorded against the targets.
>
> The objective is a comprehensive set of targets and objectives, from the boardroom to the shop floor, integrated into the day-to-day business activities of the managers and staff.
>
> (EPA, 1997, p. 8).

> The Environmental Management Programme is often described as the *engine* for continuous improvement, but an Environmental Management System, like any vehicle, is of little use with an engine alone. Hence the requirement for the additional elements which in the main are related to the housekeeping function of the EMS e.g. document control, record-keeping, corrective actions etc. (EPA, 1997, p. 7, emphasis in original)

Under the terms of their licence firms are required to develop an environmental management programme of projects and to submit an Annual Environmental Report to the EPA. Included in the AER are details of all environmental projects being carried out by the firm, with measurable goals, target dates and progress made. The EPA explicitly requires that the programme is self-developed, and, beyond requiring that firms demonstrate a commitment to continuous environmental improvement, and to the use of cleaner technology over end-of-pipe, tries to avoid prescribing projects for a firm. The regulators are keen that firms learn to develop their own solutions, and so make efforts not to impose the direction of a firm's environmental technology programme, although all proposed projects must be submitted to the EPA for approval. Where the EPA does intervene, in mandating action in relation to a clear environmental risk, they try to avoid prescribing the technology to be used, preferring firms to develop their own solutions. In order to encourage firms to set demanding goals, compliance is measured not by achievement of goals, but rather by commitment to the progress of the programme. 'Failure to meet specified targets may not result in non-compliance with the licence, *if* the licensee can demonstrate that a *reasonable* effort has been made to achieve the set target' (EPA, 1997, p. 11, emphasis in original). 'Targets set in such programmes are set to ensure that resources and systems are put in place to meet targets and the success of the Programme is to be measured by *systems in place* rather than by results in meeting targets' (Scannell, 1995b, p.1, emphasis in original). The Agency has not defined how it assesses reasonable effort, preferring not to deter firms from setting ambitious or challenging goals:

> Goals and targets can be very difficult. There is a potential for being out of compliance but I think that in the essence and spirit of co-operation I wouldn't stress that side of it so much. You might set yourself a target such as I'm going to research my process, or I'm going to research alternative processes that use less harmful materials, less harmful from an environmental point of view. Well there is no guarantee that you are going to be successful. So have you failed in meeting your objective? I would suggest that you haven't, you've tried, even though the end result might be zero from the environmental point of view. And that's why I think that compliance with the environmental management programme is something that has to be evaluated very, very carefully... And I would think that if reasonable attempts are being made to set targets and objectives and do things, that would be compliance. If they are being totally ignored, and they are totally out of step with everyone else that would be non-compliance.[16]

In its first year of implementing the new licensing the EPA was concerned solely with the licensing of the State's multinational bulk pharmaceutical manufacturers. The IPC legislation included a schedule of licensable activities and a timetable for phasing in the licensing of existing firms. The first sector to be licensed was firms employing

[16] Interview with Ian McLean, Director, IPC Licensing, Environmental Protection Agency, June 1997.

more than 100 employees, or firms using a hazardous waste incinerator and falling within Class 5.6, 'the manufacture of pesticides, pharmaceutical or veterinary products and their intermediates' (EPA, 1995, p.41). Seventeen firms were licensed in this first phase, and this cohort (with the exception of one firm[17]) forms the basis for the research in this thesis. The identification of the pharmaceutical industry as the first priority for licensing is a reflection of public concerns about the environmental impact of the industry. The evolution of environmental awareness in Ireland has had an impact on the shape of legislation, on the development of the sector, and on the strategy of Irish industrial development.

The Pharmaceutical Sector in Ireland

As part of the First Programme for Economic Expansion, the Industrial Development Authority (IDA) was established in 1956 as an independent agency with the responsibility of attracting foreign direct investment (FDI) to Ireland. A package of financial incentives was developed to encourage overseas investors: non-repayable capital grants of up to 60 percent of fixed assets, training grants, industrial credit facilities, full tax relief on export earnings and zero corporation tax. The types of incentives on offer have changed since 1956 but still remain a substantial inducement; currently the maximum rate of corporation tax is ten percent (IDA, 2001).[18]

The IDA was charged with attracting industries that best fitted Ireland's development needs. The original target, in the late 1950s, was labour-intensive industries such as textiles, paper and food-processing but it was soon realised that wage competition from the third world countries was too stiff for Ireland to be able to attract these industries with any great success. Ireland's peripheral location also meant that it was at a disadvantage in attracting industries where transport costs were a significant element of total costs. The IDA decided that Ireland was better suited as a location for

[17] Schering-Plough (Brinny) Company Ltd. was not included as the manufacturing process is markedly different, being biotechnology and fermentation based; the other 16 firms are carrying out organic synthesis or other high-solvent activities.

[18] The rate of corporation tax in Ireland is less than half the EU average (Ernst and Young, 2001). The ten percent rate applies until 1 January 2003, a rate of 12.5 percent will apply thereafter.

more technologically advanced industry with a high value added content. Consequently the IDA targeted the international chemical industry. The IDA's National Plan lists water as one of Ireland's natural resources, giving Ireland an advantage in attracting chemical companies which require large quantities of water for processing and effluent assimilation (IDA, 1979). The IDA put in place a plan to develop an industrial park specifically for chemical companies at Ringaskiddy in Cork. It developed a deep-water port at Ringaskiddy and purchased 1000 acres of land; this land bank would ensure that investors could purchase sites at fixed prices, with minimum delays in purchasing and often with outline planning permission already in place.

Although chemical companies were beginning to face increased environmental controls in the rest of Europe and the US, the IDA's strategy did not cause concern in Ireland. This can be attributed to the low level of environmental knowledge and to the severe unemployment problem which led to environmental concerns having a low priority. The general attitude of decision-makers at that time might be best summed up by a quote from an Irish politician: 'All my life I've seen the lads leaving Ireland for the big smoke in London, Pittsburgh, Birmingham and Chicago. It'd be better for Ireland if they stayed here and we imported the smoke' (quoted in Leonard, 1988, p. 126). It has been argued that the IDA was aware that part of Ireland's attraction for investing chemical MNEs was its weak environmental controls. Meetings were held with local government authorities, responsible for setting environmental standards as part of the planning process, to put the case for setting more lenient standards than those in the US and the rest of Europe (Leonard, 1988). Ultimately Ireland failed to develop a significant chemical industry presence. The oil-crisis of 1973 affected the US chemical sector badly and initiated an economic slowdown that lasted for most of the 1970s. The IDA were successful in attracting only one chemical company to Ringaskiddy, there was a dramatic drop in US FDI outflows and many anticipated Irish investment projects were cancelled.

The position of the IDA is sensitive as not only does it have to satisfy the requirements of the foreign investors but it has to ensure that the companies attracted to Ireland are acceptable to the Irish people. Prior to the 1970s there had been little resentment of MNEs, something McAleese (1972) attributes to the fact that there were no public accounting requirements (and hence no reporting of the high levels of repatriated profits) and the MNEs were producing for export and not in competition with indigenous industry. However, following some high profile cases of pollution by MNEs in the 1970s[19], concerns were raised over the direction and environmental consequences of Irish industrial policy (Allen and Jones, 1990). An Taisce, a moderate and well-respected heritage organisation, articulated some of this concern when the chairman stated that 'of all the economic incentives the Irish government offers to foreign industry to invest here the most valuable is the permission to pollute.'[20]

The IDA responded quickly to the charges of environmental exploitation and criticism of its role in attracting polluting industries. It began to promote itself as a guardian of the Irish environment and in 1972, citing as a reason the weak and uncoordinated nature of Irish environmental legislation, the IDA instituted a policy that all projects seeking IDA funding were required to carry out an environmental impact assessment to standards established by the Institute for Industrial Research and Standards. In 1976 the IDA published a survey of pollution in Ireland (IDA, 1976) that found many examples of clean and responsible industrial plants and few environmental problems (mostly attributed to the agricultural sector). At this time the IDA began to target the pharmaceutical and fine chemicals sector. A number of factors made for a happy alliance between the IDA and the multinational pharmaceutical sector. The pharmaceutical firms were attracted not only by the package of financial incentives offered by the IDA but also by access to the high-growth European healthcare market after Ireland joined the European Economic Community in 1973. Their profile as a high-value added, high-technology, recession-

[19] Such as the public opposition to the Raybestos Manhattan plant in Ovens and the Gulf Oil terminal disaster in Bantry Bay (Allen and Jones, 1990).

[20] Quoted by Mary Holland in 'The Pollution of Killarney', Washington Post, 6.8.1978, p. F-8, cited in Leonard and Duerksen (1980, p. 61).

proof industry with few visible pollution problems made them an ideal choice from the IDA's point of view (Leonard, 1988). This view is still promoted by the industry itself, such as this statement from the trade organisation Irish Pharmaceutical and Chemicals Manufacturers Federation: 'It is commonly accepted that Ireland has the fastest growing pharmachem industry in the Western World. It is a high value, *clean*, niche sector which has an excellent strategic fit with the Irish economy' (IPCMF, 2001, emphasis added).

Despite the views of the IDA and the industry, the perception of society was not as positive. During the 1980s concern about environmental damage from the sector grew. A Cork Examiner/IMS poll in 1989 found that 80 percent of the general public believed that the pharmaceutical industry was responsible for environmental damage. While local authorities usually welcomed the employment and income generated by new plants, protest and opposition by non-governmental organisations became more vocal and high-profile.

A number of incidents during the late 1980s show how the industry began to come under pressure from both regulators and public opinion. In 1987, Merrell Dow, a large US pharmaceutical company, announced plans to locate in Cork. The company decided to locate away from existing pharmaceutical plants, claiming this demonstrated their commitment to high environmental standards as any pollution problems would be instantly attributable. Local residents challenged the planning application and a lengthy appeal followed. Although Merrell Dow won the appeal the project was subsequently cancelled. The reason given for the cancellation was that following a merger with another company the new capacity was no longer required; there is some doubt about this claim as Merrell Dow has subsequently invested in a new plant in Spain. In 1989 there were the first prosecutions of pharmaceutical companies for breaches of pollution standards. Two pharmaceutical companies in Cork were prosecuted for breaches of the 1987 Air Pollution Act and were fined the maximum of £1000. In 1989 the Supreme Court found pollution from a pharmaceutical company responsible for severe damage to the health of a farmer, his family and his herd. The court determined that the firm should pay compensation of over £1 million. In 1989 Sandoz[21] announced plans to locate in Ringaskiddy. There were immediate and vociferous objections to these plans. Environmentalists cited the Basle disaster when a fire at a Sandoz plant led to extensive pollution of the Rhine and claimed that Sandoz were locating in Ireland to avoid stiff Swiss environmental controls. Sandoz was initially granted planning permission and also won the subsequent planning appeal. A Cork couple then exercised their constitutional right to a judicial review of the proposed plan. Sandoz faced an 18 month delay to its investment plans and the prospect of continued scrutiny from environmental groups. A member of one such group, Cork Environmental Alliance, stated that they would make an example of Sandoz and that the firm would have to pay the price for the past environmental abuses of other pharmaceutical plants. It is probable that Sandoz persevered with its investment plans because it was sensitive about its reputation as an environmentally responsible company. The consequences of being seen to cave in to environmental pressure would have generated very damaging adverse publicity and would support the claim that Sandoz were locating in Ireland because of lax environmental controls.

These concerns and protests by activists have been labelled by the IDA and government officials as an 'overuse of democracy' (Culliton, 1991). As early as 1980 the IDA made clear its position on the relative priorities of industrial development and environmental protection in a statement which warned that adverse publicity from small pressure groups would deter investment and cost jobs. Developments in the 1980s suggest that adverse publicity did have the power to deter investors. No significant new bulk manufacturing facility has been attracted to Ireland since the Sandoz investment in 1989. With limited resources, the IDA cannot risk investing effort attracting pharmaceutical companies to Ireland if projects are going to be jeopardised by public hostility. The IDA's development strategy for the 1990s has been to focus on attracting investment from the high technology, lower-pollution electronics sector. Ultimately, public concerns about the environmental impact of the

[21] Now known as Novartis, after a merger with CibaGeigy.

pharmaceutical industry were reflected in the introduction of IPC licensing. The first sector to be licensed was firms engaged in 'the manufacture of pesticides, pharmaceutical or veterinary products and their intermediates' (EPA, 1995, p.41) and employing more than 100 employees or using a hazardous waste incinerator.

The regulatory regime has gradually converged with EU and international standards, but to date no pharmaceutical or chemical company that has been introduced by the IDA has ever left Ireland (IPCMF, 2001). Many of these companies have continued to expand their Irish operations. Half of the firms in this study have announced substantial investment plans (total value in excess of £1.2 billion) in the period 1994-2000 (IPCMF, 2001). Generally expansion investment is competed for by plants within a corporation and is awarded on the basis of plant competitiveness. If low environmental control costs were significant in underpinning the competitiveness of plants, to the point of being a determining factor in location, it is unlikely that Irish plants would continue to secure investment to expand. There is no evidence to support the public perception that pharmaceutical companies locate in Ireland to avail of lax environmental legislation.

The Irish pharmaceutical industry is a sub-sector of the fine chemicals and pharmaceutical (or pharmachem) sector. There are approximately 140 firms in this sector, about 120 of which are branches of multinational companies, with a small number (20 firms) of indigenous companies. In 1997, exports from this sector were worth $18 billion and made up 25% of Ireland's total exports, making Ireland one of the largest pharmachem exporters in the world (IDA, 2001). The pharmaceutical sub-sector is made up of 80 firms, which in 1997 employed 12,100. The largest and most significant of these plants were identified by the EPA licensing procedures. To date, 34 firms have been issued IPC licences for 'the manufacture of pesticides, pharmaceutical or veterinary products and their intermediates' (EPA, 1995, p.41). The licensing took place in two phases: firms with more than 100 employees or operating a hazardous waste incinerator fell within the first phase, and were required to have submitted an IPC licence application by September 1994. Seventeen plants fell within this category, and were large, multinational plants and, with the exception of one plant, engaged in bulk organic synthesis of pharmaceutical active ingredients. Smaller firms (employing less than 100 employees) were required to have submitted an application for licensing by March 1996. Seventeen firms fell within this phase, and are small-scale manufacturers of intermediate and finished pharmaceuticals. The research in this study focuses on the sixteen organic synthesis plants licensed in the first phase of IPC licensing.

The structure of the pharmaceutical industry in Ireland is different to the structure typically found in other EU countries. In most EU countries the industry is made up of the second stage of production, which is the packaging of the intermediate product into finished goods, in the varying dosages and formulations required by local markets. While not as technology-intensive as the primary stage, this stage requires knowledge of local market conditions and regulations. While this kind of production was not actively targeted by the IDA, as the sector has developed there has been new investment in finished pharmaceutical plants, with approximately 50 plants now operating in Ireland.

Industrial policy in Ireland was to target the first stage of pharmaceutical production, which is the processing of active ingredients, typically through organic synthesis in batch plants. This stage is a capital-intensive, high technology and highly-skilled process characterised by large economies of scale. It is also the most pollution-intensive process: 75 percent of pollution generated by pharmaceutical production is generated during the processing of active ingredients (Keohane, 1989) and the ratio of waste to product is often in the order of 10:1 (Cunningham and Moriarty, 1993). Each multinational pharmaceutical company has at most two or three such plants which are usually located in the firm's home country or in a low-cost tax-haven. This is the type of operation the IDA has attracted to Ireland. The pharmaceutical sector in Ireland is largely comprised of foreign owned multinational subsidiaries manufacturing intermediate products for intra-firm export to packaging plants in the rest of Europe and the world. Nine of the 13 top pharmaceutical firms in the 1999 Fortune's Global 500 corporations (Fortune, 2001) have bulk manufacturing plants in Ireland.

For the Irish pharmaceutical sector, environmental management has become a strategic business issue. The IPC regulations are demanding, and reflect the regulator's intention to secure continuing reduction of environmental impact. Firms that are not able to implement effective environmental management risk limiting their 'flexibility of action' (Hoffman, 1997, p. 6) as the demands of the licence will act as a constraint on their activities.

The EPA has strong powers to deal with non-compliance and can have a serious impact on a facility's operations. The most extreme sanction, and one that has never been exercised, is that the EPA has the authority to close down a facility. Non-compliant facilities also face other limits on their behaviour such as fines and court proceedings. Unannounced audits are used to investigate firms with persistent and unresolved problems. In these cases the EPA may oblige the firm to implement a particular solution or may compel the firm to cease a particular activity. Non-compliant companies are also named in the annual IPC report, as well as having details of all problems on file and publicly available at the EPA.

Community approval is an important constraint for these plants. Plants that have not built trust with the community have found their flexibility of action constrained when it comes to obtaining official licenses, such as planning permission and IPC licences, as seen in the case of Sandoz. Firms that do not meet their IPC responsibilities are open to more than just EPA censure. The law is also open to the community: '... non compliance with a licence, even in a minor respect, could destroy a defence to civil actions brought for damages under section 20 of the Local Government (Water Pollution) Act or section 28B, inserted by section 18 of the Environmental Protection Agency Act 1992, of the Air Pollution Act 1987'. (Scannell, 1995b, p. 1). Firms that have a strategic outlook recognise that they require an unofficial licence to operate from their neighbours.

Environmental control costs have always been significant for this sector. The Federation of Irish Chemical Industries (FICI) estimates that total spending on environmental compliance up to 1987 was £95 million[22]; this compares to spending of approximately £200 million in the period 1988-1994 (Buckley, 1992), associated with the introduction of air pollution standards and licences in 1987. In the last new plant built in Ireland, by Novartis in 1988, environmental control costs were £35 million or 20 percent of the total investment of £205 million. Multinational pharmaceutical companies do not have a problem with making large capital investments for compliance. They are generally happy to invest in end-of-pipe technologies as long as they can be installed and operated without affecting the production process, and as long as any given investment ensures compliance for a long period. Now however tightening environmental standards are approaching the technical and financial limits of abatement technologies' ability to achieve these levels of environmental protection. 'The marginal costs of pollution abatement are ... rising. Easy problems have mostly been fixed, and the remaining obstinate challenges are becoming increasingly expensive to resolve' (Colby et al., 1995, p. 2). The regulator has recognised that source reduction, that is, changes to the production process that reduce the waste being produced, will be the only economically and technically feasible solution to attaining the high standards demanded by society. Regulators have embraced cleaner technologies because of the win-win possibilities; these technologies have the potential for both increased environmental protection and cost-savings, since physical waste usually represents economic waste (Porter and van der Linde, 1995a).

However pharmaceutical firms, by the nature of their products, face a number of sets of compliance requirements, some of which constrain their ability to exploit cleaner technologies. Costs of developing a new drug are very high, in the order of $300-$600m. Companies have 20 years of patent protection within which to covers costs, fund future development and make a profit. The period of patent protection begins

[22] The Sunday Business Post 7.4.91

before the drug is ready to market, while regulatory approval is being obtained. New products, or new chemical entities (NCEs) have to be approved by national regulatory bodies (such as the US FDA) before they can be marketed. Once approval has been given the process by which the compound is synthesised, or the chemical route, is fixed and cannot be changed. The high costs of development mean that companies are anxious to get their products onto the market quickly, which means that they file for approval as soon as possible. They also want to maximise the effective patent life, so they are reluctant to delay or revisit the licensing process. The constraint that this places on source reduction and cleaner technologies is that firms have weak incentives to file an NCE that has been optimised for efficient and low waste production. Often compounds are file based on the chemical route developed at bench-scale in the development laboratory, without any consideration of the manufacturing issues. When a compound does go into full-scale production, firms are very reluctant to go back to the regulator to change the route, as this is costly and may require extensive new trials and filing. Furthermore, plants that wish to sell into the US market must have their production facilities approved by the US FDA for compliance with their standards of manufacturing, Good Manufacturing Practices (GMP). These establish minimum standards for process procedures and documentation. They also compromise the plant's ability to reduce waste: recent tightening of cleaning standards specified that plants may not reuse solvent for washing vessels but must use virgin solvent, increasing both energy and solvent usage.

Notwithstanding the constraints faced by this sector, the requirements of IPC for effective environmental management and the use of cleaner technologies represent a strategic opportunity for the sector. Technology Foresight Ireland was an initiative which examined key sectors of the Irish economy to identify 'future-proof strategies which will ensure that the science and technology infrastructure … has the capacity to promote innovative industry into the future' (ICSTI, 1999, section 1.2). The Chemical and Pharmaceutical Sector Panel identifies global trends in the industry. The panel predicts that the future of the sector will be characterised by further mergers, leading to excess capacity and consolidation and the emergence of larger 'super-research' and 'super-manufacturing' sites. Plants in Ireland are in a good position to survive the consolidation process and develop into 'super-manufacturing' facilities 'as the sector in Ireland has an internationally established reputation for excellence in process development and manufacturing and is well placed to be a global centre' (ICSTI, 1999, section 3.3).

The panel assessed the key future drivers and technologies affecting competitiveness of these plants. Manufacturing plants will be expected to manage more complex processes, with earlier new product transfer to manufacturing (in order to reduce time-to-market). Increased pressure for cost containment and higher purity levels will require tighter control of the manufacturing process, achieved through process optimisation, increased process control, and the use of novel manufacturing technologies for reduced energy use and waste production.

The findings of the panel are supported by research in this area. Traditionally in the pharmaceutical industry, the potential sources of competitive advantage did not include manufacturing, but were derived from advantages in R&D, management of clinical trials and registration, or marketing and distribution (Henderson and Cockburn, 1994b). Pisano has argued that institutional change has altered the 'competitive dynamics of the pharmaceutical industry (1997, p. 59). Increased buyer power has reduced price premiums and tighter drug regulation has increased drug development times and eroded the effective patent life. There is now important competitive leverage to be gained from cost savings and reduced time to market achieved through effective manufacturing capabilities. This suggests that, given these changes, Irish pharmaceutical manufacturing plants will have to be competitive with other plants within the same corporation. They are under threat from the trend towards increased outsourcing of complex and specialised processes. Cleaner technologies will have a role to play in ensuring the cost competitiveness of plants. More importantly the technical capabilities that underpin the effective introduction of cleaner technologies, namely deep understanding of production processes and integrative organisational processes for co-ordinating technical change, are the capabilities that will be crucial to managing cost containment, flexibility and reduced time to market with processes of increasing complexity. In addition, environmental management and regulation are recognised as important institutional factors that have an affect on the sector. The panel identified four strategies as important for 'making Ireland a still more attractive location in which to manufacture' (ICSTI, 1999, section 3.4). Two of these strategies reflect the role effective environmental management plays in supporting sector competitiveness.

'Rapid Response Regulation' is a strategy that recognises that for this sector 'one of the major challenges' (ICSTI, 1999, section 4.3) is compliance with regulations (environmental, health and safety, as well as FDA). The strategy aims to 'ensure that Ireland is the most favourable location in the world in which to meet properly stringent national and international regulatory requirements' (ICSTI, 1999, section 4.1), recognising that 'a responsive regulatory environment will be necessary to support the existing manufacturing plants as they compete' (ICSTI, 1999, section 3.3). 'Hearts and Minds' is a strategy that aims to improve the sector's reputation with the wider community, specifically to overcome difficulties in the supply of skilled labour.

Conclusion

Central to the licensing philosophy is continuous improvement and a shift of emphasis to pollution *prevention* rather than pollution *treatment.* Firms are required to meet standards for the emission of pollutants, but above that they are required to demonstrate a continuous effort to upgrade their environmental performance: 'the EPA views an IPC licence as dynamic in nature reflecting ongoing improvements in technologies ... at each site' (EPA, 1998, p. 9). They specify that firms put in place environmental management and information systems. Firms must also establish an environmental management plan (EMP) that sets goals and reports on progress. 'These goals take the form of objectives and targets to minimise and where practicable eliminate adverse environmental effects... The targets set are expected to be demanding of the licensee and require effort to achieve them' (EPA, 1998, p. 10).

Firms that are able to respond to the new requirements by developing effective environmental management will be able to avoid the threats associated with non-compliance from both the regulator and the local community. By implementing cleaner technologies, these firms will have an advantage in managing the costs of compliance and the demands of future regulations. They will benefit from enhanced reputation and risk management. There is also the potential to develop and upgrade technical capabilities that support strategic advantage. On the other hand, firms that do not develop an effective organisational response to the new legislation will face forced rather than planned change as well as severe limits on their flexibility of action.

Assessing the success of this new regulatory approach requires an assessment of firms' ability to comply with the requirements of the regulations and an understanding of the impact on firms of achieving compliance. The identification and development of an appropriate theoretical framework for pursuing this analysis is the subject of the next chapter and the following chapters four and five.

3: Environmental Regulation and Industry Competitiveness

Introduction

This chapter will explore the foundations of environmental economics, looking at the research areas covered, the type of analysis used and the possible limitations of this approach for looking at issues characterised by uncertainty and novelty.

The Development of Environmental Economics

The development of environmental economics has been driven by the increasing political and social importance of environmental issues. 'The evolution of environmental policy, both in the US and elsewhere, has inevitably brought economic issues to the fore' (Cropper and Oates, 1992, p. 676). As environmental policy-makers have faced difficult decisions in balancing environmental protection against the high costs of such policies and the impact on economic growth, so the influence and academic standing of environmental economics has increased. Prior to the 'environmental revolution' (ibid., p. 675) in awareness in the late 1960s, environmental economic theory was not an established research programme but an application of the microeconomic theory of externalities and market failure.[23] Apart from some notable exceptions, which will be discussed later in this chapter, environmental economics is still predominantly characterised by the neoclassical economic analysis of environmental issues. 'Most environmental economics is being carried out within this framework, and, more importantly, ... the most influential work in the subject is of this kind' (Jacobs, 1994, p. 67).

Neoclassical Environmental Economics – An Overview

The foundation of environmental economics is the conception of the environment as a scarce resource, one that could ultimately act as a constraint on economic growth. The central role of efficient resource allocation in mainstream, neoclassical economics facilitated the development of environmental economics as an application of neoclassical analysis, using the analytical tools of welfare economics (Munday,

[23] Environmental examples are often used to illustrate welfare theory in standard economics textbooks.

1996). Making environmental questions tractable to neoclassical analysis requires the 'commodification' of environmental resources, allowing the determination of market prices for these environmental goods and the development of environmental policies to correct for the absence (failure) of markets in environmental goods (Jacobs, 1995).

Property rights are 'a bundle of entitlements, privileges and limitations defining the owner's rights to use a resource' (Tietenberg, 1994, p.31). With properly defined property rights, where all the benefits and costs of a resource accrue to the owner, abuse without compensation cannot take place.[24] If nobody 'owns' the environment, a firm does not have to include any element of cost for environmental damage in its production decision, even though it imposes an external cost on others. This uncaptured cost is known as an externality. In essence an externality arises when a decision or transaction has an associated cost or benefit that affects an involuntary third party to the transaction but does not affect the decision-maker. 'When transactions exhibit important external components, free-market production and exchange cannot allocate resources to their most valuable uses' (Call and Holahan, 1983, p. 452).

A profit-maximising firm will take advantage of a free resource to produce more goods and pollution than is socially desirable. The environmental abuse (or overuse) that is seen in practice is due to market failure. This stems from the public good nature of many environmental resources and the difficulty of establishing property rights. Environmental resources are both non-rivalrous, in that one person's consumption does not decrease the amount available to others, and non-excludable, in that it is not possible to prevent consumption of the good. This makes it difficult for a self-organising market to operate, since free-riders cannot be prevented from using environmental resources without paying; this has implications for the efficient use of environmental resources. If environmental resources were private goods any increase in their scarcity would be reflected in an increase in their price. This would act as a

[24] Coase (1960) suggested this situation where regulation is not necessary as the parties involved can negotiate compensation. This is very much a special case that requires small numbers of affected parties as with large numbers the transaction costs of reaching a settlement become prohibitive.

signal to firms, increasing their production costs and encouraging them to decrease their use of the resource, either by limiting output or by substituting with a less scarce input. The market would self-regulate, equating the private benefits of the resource (reflected in the price firms are willing to pay) with the social costs (reflected in the price society would accept for use of the resource).

An example of this would be a pharmaceutical plant that emits pollution to the atmosphere. If waste disposal is a necessary part of production then air emissions can be considered as an input into the manufacturing process, in addition to the other inputs such as raw materials, energy and labour. In using the air to dispose of waste, the plant gains a benefit, measured as the marginal private benefit of emissions to the firm. However, the air is not only of benefit to the plant, but to the rest of the community.[25] The community derives a benefit from the air, but this benefit is reduced if the pharmaceutical plant's air emissions lead to a degradation of air quality. This degradation is quantified as the marginal social cost, borne by the community, of air emissions by the plant. If the pharmaceutical plant were required to pay for its use of the air, then it would be likely to economise on air emissions; as long as air emissions are effectively a free input then firms have an incentive to maximise their use. In the absence of established property rights and a free market for air use, environmental policy can balance the conflicting demands of industry and society. In this analysis, policy can achieve the most efficient use of the resource by setting the price of air emissions to achieve a level of pollution at the point where the marginal private benefits to the plant are equal to the marginal social costs to society. At this point 'any more protection will not be worth its costs, while any less will undervalue the benefits the environment provides' (Jacobs, 1995, p. 51), so policy to achieve this level ensures that environmental damage is kept to an optimal level as determined by societal preferences.

Jacobs (1995) draws out the core tenets of the neoclassical approach that underpin the characterisation of environmental issues outlined above. The primary objective of

[25] Depending on the type of pollutant, this may be the global community.

neoclassical theory is optimal allocation of resources with respect to societal preferences. The determination of societal preferences is achieved by the adoption of methodological individualism, which holds that individuals should be the unit of analysis and that all social structures can be explained with reference to individuals. Desired levels of environmental protection for society can therefore be established through the construction of a demand curve for environmental goods that is the summation of individual preferences over a series of environmental quality/price combinations. Establishing these preferences is possible by the assumption of the rational economic person, who wishes to maximise individual utility. Mathematical tractability requires that these preferences are determined exogenously and are unchanging over time.

Technology is also assumed to be an exogenous element. The neoclassical model assumes either perfect information or, at least, bounded rationality. As will be seen below it is these traditional models that have been used by neoclassical environmental economists in their limited exploration of questions of regulation and induced innovation (Kemp, 1997; Jaffe et al, 2000). Notwithstanding the development of some recent neoclassical approaches that take into account endogenous technical change (such as Romer, 1990, 1994), it remains broadly the case that in the neoclassical models there is no consideration of what Knight (1921) terms 'radical uncertainty', that is situations of uncertainty where even the range of possible outcomes cannot be estimated or assigned probabilities. Agents are assumed to have the same cognitive framework, the same unlimited cognitive competence. The assumption of rational optimisation is incompatible with any element of learning, which implies a period of suboptimal knowledge. There is no allowance for trial and error search, no creativity (or uncaused cause, in Veblen's term) (Hodgson, 1996).

The final tenet of neoclassical environmental economics is that the allocation of resources is achieved most efficiently through the use of competitive markets and that 'the appropriate level of environmental protection is derived from market transactions' (Jacobs, 1994, p. 68). Market analysis is central to both of what Jacobs

(1995) identifies as the two stages of the neoclassical project, that is, (i) establishing environmental objectives for policy and (ii) achieving environmental objectives through policy.

In stage (i) environmental economists hold that they are neutral about what level of environmental protection should be chosen. Their contribution is that the institution of objective setting should be market-based, namely the outcome of cost-benefit analysis (CBA). This is one of the core areas of environmental economic research, and has involved the development of techniques for establishing a value for unpriced environmental resources through imputed markets. Hedonic pricing methods derives a value for environmental benefits from the prices of related, real markets that carry information on consumer choices - such as house prices and labour wages.[26] The contingent valuation method establishes consumers' willingness-to-pay for environmental resources through direct questioning. The other half of the analysis is the development of an environmental supply curve from the costs of environmental protection, though this receives less attention within the discipline, since 'it is widely assumed that the supply side poses few conceptual problems' (Jacobs, 1994, p. 71). Together the derived environmental demand and supply curves form an imputed market for the environmental good, and from the equilibrium of supply and demand the optimal level of protection can be established.

In stage (ii) environmental economists aim to establish the most efficient policy instruments to achieve environmental objectives. Work in this area looks at the efficiency of different policy instruments, with the main focus on the superiority of market-incentive based instruments (environmental taxes and permits) over standards-based policy. Market-based instruments allow individual firms to determine the most efficient level of pollution, based on their own cost structures. Firms that can reduce pollution at a low cost will do so, whereas firms with less advantageous cost structures will prefer to pay the permit price or tax. Standards-based regulations mandate a single response from firms; the result is that some firms

[26] For example, a comparison of house prices between a location near a pollution source and a hazard-free area is used to reveal the monetary value placed by consumers on that level of environmental quality.

may not reduce pollution as much as they could, while other firms may be forced to pay very high pollution control costs to achieve the standard. 'It is easy to show that, if markets are competitive and economic agents are rational, the use of ... [market-based] instruments will achieve the desired level of environmental protection most efficiently: that is, at least total cost to society' (Jacobs, 1994, p. 73).

The impact of cleaner technology is analysed within both stages. Stage (ii) theoretical models are used to look at the potential of regulatory instruments to induce technical change. Stage (i) assessments of the costs of environmental protection may include an exploration of whether technical change has reduced the burden of compliance. The following discussion of the literature will show that relatively little attention has been given to these questions. The focus of the discipline is on questions of environmental valuation and market-based instruments. The limited interest in this question may be a function of the limited ability of the neoclassical framework to explore questions characterised by uncertainty and novelty.

Neoclassical Models of Environmental Regulation and Innovation

Downing and White (1986) model the effects of policy instruments under differing firm and regulator conditions in order to assess the relative efficiency of the instruments with respect to social benefits and costs. The policies considered are: emissions standards; emissions taxes; emission control subsidies and marketable permits. A permit policy allows the regulator to set the overall, allowable quantity of emission of a pollutant (ideally at the level that equates the marginal social damage of the pollutant with the marginal social benefit of the associated production). Permits are issued, allowing firms to emit up to that level, and this creates a market for emissions, allowing firms the choice of abating the pollutant or purchasing a permit to emit the required quantity. The benefits of this system are that it encourages the burden of abatement to fall on those firms that are the most efficient, thus minimising private and social costs. This can be achieved by using an emissions tax, but an advantage of the permit system is that it allows the regulator to set the quantity of allowable pollution; under an emissions tax based system the regulator would only be able to determine the quantity of pollution if it knew the industry's marginal cost of abatement curve. Emissions standards also allow the regulator to set the level of pollution, but are not economically efficient as all firms must abate to the same standard, regardless of firm differences in abatement costs.

The firm is assumed to have perfect knowledge of future tax levels and legislative responses, and maximises the present value of profits less investment costs. The firm faces the decision of maintaining its existing abatement technology and levels of emission or investing a known amount to move to a superior technology which would (1986) allow reduced abatement costs and a higher level of emissions. Downing and White derive the minimum level of gains necessary to induce such an investment in a firm, under different policy instruments, and in a number of different scenarios. Regulators are presumed to set policy goals at the point where the marginal cost of abatement to industry equals society's marginal demand. This can be done either by setting policy with respect to the emissions level at this point (standards based regulations) or by using the marginal cost/price of emissions at this level (either as an effluent fee, subsidy or permit price).

The first scenario is where the firm is small enough that changes in its level of emissions do not change the optimal emissions level. The second scenario is where the firm is large enough that its innovative behaviour shifts the industry marginal abatement cost curve but the regulations remain unchanged. The third scenario is again where the firm is large enough that its innovative behaviour changes marginal conditions, and the regulator reacts by tightening the regulation to achieve the new, socially-optimal, level at which MC=MD.

They find that in all three scenarios, regulation by standards does not provide adequate incentive for innovation. Furthermore, even with market based instruments, the socially optimal levels of innovation and emissions may not be achieved in situations where the polluter is large enough actually to change the social marginal conditions. If the regulator did not respond by tightening regulation, then firms would have an incentive to innovate to a level that exceeds the socially optimal level. The marginal social cost of pollution damage curve is assumed to slope upwards, that is, the marginal cost is assumed to increase as the level of pollution increases. Conversely, if an innovation is significant enough to reduce the total amount of pollution, this moves the socially optimal level and cost/price of pollution back down the marginal damage curve. If regulators do not reflect this change by reducing the costs of emissions fees to industry, then private gains from innovation will be calculated using a higher cost of pollution than the actual social gains. Innovations may be adopted because they lead to private gains for the firm, but without realising social gains. To prevent this happening the regulator should respond to the changed marginal conditions by tightening or ratcheting the regulations. However with some market-based instruments, this tightening process could reduce the incentives to innovate to below the socially-optimal level. The authors' overall conclusion suggests that regulators require information on the nature of polluters and innovations before being able to choose the optimal policy.

Malueg (1989) considers whether emission permit policies offer increased incentives for innovation. Malueg's model is similar to Downing and White's. The firm faces a choice between the existing abatement technology or investment of a known amount to achieve a known, lower marginal abatement cost curve. It is assumed that abatement is costly and that the profit-maximising firm will therefore not voluntarily abate beyond the regulated amount. Under a system of emission standards the firm's gain from investing in innovation is restricted to the reduced cost of abating up to the level of the standard. Under a permit system the firm does not face a limit on its emissions, it can pollute beyond its abatement capacity by buying permits. It will abate up to the point where the marginal cost of abatement equals the permit price; where the marginal cost is less than the permit price it is cheaper for the firm to abate its emissions, while once it gets to the point that the marginal cost exceeds the permit price the firm will pollute and buy the necessary permits. In this situation the firm's gain from innovation is (a) the reduced abatement cost at existing levels and (b) the saving of the difference between permit and abatement costs on an increased level of abated emissions. Malueg then goes on to illustrate the special case of a firm that faces a high marginal abatement cost function, such that under an emissions standard policy the firm would be abating at a high private (and social) cost. Under a permit system such a firm would choose to abate much less, and would buy permits to cover the remaining emissions. If this firm could only achieve a slight improvement in its marginal cost curve through innovation then the gains would be slight, although it would abate a higher amount and so purchase fewer permits. The corresponding gains would be higher under a system of standards, as the per unit cost benefit would be applied to the higher level of abatement. Malueg thereby shows that the incentives to innovate are not uniformly higher under a permit system, but he ignores the social costs of a standards system that forces high, non-optimal levels of abatement on firms, above the social benefits.

Magat (1978) presents the first formal model of the effects of environmental regulation on innovative behaviour in firms. He builds a dynamic model of a firm in which investment decisions by the firm affect the rate of growth. The firm in this model is a price-taking firm using a single input to produce a single product output and a waste product. Abatement treatment of the waste is assumed to require use of the input. The firm has the choice of allocating R&D investment to improving either production technology or abatement technology. The firm is assumed to maximise immediate profits (this is a 'myopic behavioural assumption' (ibid., p.11) whereby the firm is unaware of future costs, prices and tax levels) by locating its R&D allocation along a known innovation-possibilities frontier, a function analogous to the standard production-possibilities frontier, that traces out the possible combinations of production and abatement technology achieved from a given R&D investment. The pattern of investment is also influenced by the substitutability of labour between production and abatement.

Magat compares the impact on innovation of regulation by emissions tax and by emissions standard, analysing the effect over time on production, waste outputs, and the rate and pattern of R&D. Standard and taxes will have different impacts on the composition of R&D investment, and the results are ambiguous. In the situation where there is poor labour substitutability, regulation by standard will induce technical advance in both production and abatement technology. However, in this situation, the use of a tax on waste will lead to divergence, with production technology receiving an increasing relative share of investment over time. If it is relatively easy to substitute labour between production and abatement use, the impact is somewhat different. The use of a tax will see the emergence over time of an increasing relative share of investment being used for innovation in abatement technology. The use of a standard induces a pattern that is sensitive to the initial circumstances, resulting in either abatement technology or production technology gaining an increasing relative share of investment. The model shows that, despite regulation, the firm can use technical advance to maintain growth, albeit at a reduced level compared to the no regulation situation.

Biglaiser and Horowitz (1995) present a model of the payoffs and incentives of environmental technology research. They use this to examine the requirements for efficient, research-inducing regulation and the incentives to firms to engage in research and to adopt new technology. Their model assumes perfect competition, with homogenous, price-taking firms that are 'equally capable and in identical industry positions before undertaking research' (ibid., p. 666), although they accept that these assumptions do not always apply in reality, and that 'firms will often have different abilities to conduct research due to having done research in the past' (ibid., p. 679). Unlike the previous models discussed, the outcome of the research is not known, although neither is it truly uncertain, as the results of each firm's research is drawn from a known probability distribution. Firms face the decision of whether or not to engage in research; firms that do not research, or fail to develop viable technologies, can license technology from other firms. Social efficiency is achieved by setting a tax that internalises the cost of marginal social damage and includes it in the private marginal costs of production. Social efficiency is maximised where all firms adopt the most efficient technology but, given a cost for adoption, profit-maximising firms will choose a socially sub-optimal level of adoption. Biglaiser and Horowitz suggest that to maximise social efficiency regulations should include, in addition to an emission tax, an adoption standard that requires firms to adopt a defined minimum standard of technology. This standard should be implemented by establishing the minimum socially efficient technology, i.e. the technology with an associated payoff just equal to the payoff from the best technology net of the costs of switching. The adoption requirement would only apply to firms whose technology falls below this cut-off technology. The regulator has a choice in the level of the technology standard enforced. Mandating adoption of the best technology will maximise social welfare but it will also mean that there is no competition in the technology licensing market and the appropriation of the rent from adoption will be decided by a bargaining game between the licensing firms and the licensees. Social efficiency is maximised by allowing adopters to adopt any technology above the cut-off level; this will also have the effect of reducing the rent that any firm can earn. Biglaiser and Horowitz then explore opportunities open to the regulator to increase research and social welfare. They find that increasing the emissions tax reduces the number of firms undertaking research. This is because the better a firm's technology, the less is the impact of the tax increase; the firms with the best technology are the firms that developed the best technology and the non-researching firms that adopted this technology. A higher emissions tax will increase the incentives for licensing over researching, although 'given the (ex post) technology vector, the best firm may profit from an increase in the emissions tax' (ibid., p. 676). Changing the adoption standard will reduce the number of firms undertaking research. A stricter standard (i.e. a higher cut-off level) will increase the risk of unsuccessful research, and so increase the attractiveness of licensing technology. The only way regulators can increase the number of firms engaging in research is to restrict the range of allowable adoption technologies. This move would increase the expected profits of the researching firms, and decrease the profits of the adopting firms and so increase the attractiveness of engaging in research.

Wiersma (1991) examines the relative efficiency of different policy instruments, comparing models with and without technical change and learning effects. He develops a static, empirical model of the Dutch electricity industry between 1985 and 2000 and uses it to simulate the effect of sulphur emissions policy, showing that a move from the existing standards approach to an emissions tax would yield total cost savings of 12%. He then develops the model to incorporate learning effects. He does this with a learning curve, which relates unit cost reduction to cumulative output. He uses studies of learning curves in a number of US industries, combined with engineering case studies of cost reductions in industry abatement technology, to estimate a learning curve for abatement in the Dutch electricity industry. Although the model is an attempt to incorporate more realistic features of the dynamic effects of learning, it still relies on some strong assumptions. Wiersma assumes the nature of the relationship between experience and compliance costs, without any direct empirical testing of the assumed relationship. He assumes that learning functions estimated in other industries, in other countries and not relating to compliance can be extended to provide accurate estimates for this industry. Using the estimated learning curve, he then simulates the effects of policy instruments. He finds that the costs of emissions standards are ten percent less than the static estimate. The emissions tax policy is again more efficient, with costs 24 percent less than standards-with-learning and 21 percent less than the estimated costs of the tax policy in the static model.

Regulation and Competitiveness - Empirical Research

The main outcome of neoclassical theoretical models, such as those outlined above, is that regulation is always costly and moves firms away from their optimal, profit-maximising position. On this basis the theory proposes that a country introducing stringent environmental controls has a reduced natural resource endowment[27] and faces an erosion of its comparative advantage in pollution-intensive production. Empirical studies of competitiveness and environmental regulation have sought to determine the impact of environmental policy on output, balance of trade and foreign direct investment. Some studies look for changes in comparative advantage as reflected in the pattern of trade. Revealed comparative advantage in pollution-

[27] The resource endowment is determined by the social and physical tolerance for waste assimilation; a reduction in this tolerance would not affect industry until it is reflected in regulation.

intensive production is shown if products from the sector in question account for a higher proportion of a country's total exports than they do of total world exports. Other studies test the pollution haven theory by modelling the determinants of FDI inflows and seeing if the laxity of environmental standards is a significant explanatory factor. The results are mixed: some studies have found no conclusive evidence whilst others have demonstrated a discernible impact on comparative advantage attributable to environmental policy. A survey of over a hundred empirical studies concluded that there is 'little evidence to support the view that US environmental regulation has a large adverse effect on competitiveness' (Jaffe et al., 1993, p. iii).

Another group of studies tries to estimate the impact of regulation on industrial productivity growth, at nation, industry and plant levels. This approach has been described as 'more fundamental, though possibly less direct' (Jaffe et al., 1993, p.150), referring to the fact that these approaches consider national productivity in isolation and ignore the impact of trade effects. Some of these models include the effect of learning and technical change. 'To the extent that regulation inhibits investment and/or slows productivity growth, this can be viewed as indirect evidence suggesting that induced innovation effects are either small or are outweighed by other costs of regulation (Jaffe et al., 2000, p. 28).

Gollop and Roberts (1983) look at the effect of environmental regulation on the US electricity industry. They assess three factors affecting productivity growth, over the period 1973-1979, which saw the implementation of the 1970 Clean Air Act Amendments. They model compliance as the switch from high-sulphur coal inputs to low-sulphur coal inputs. They derive a measure of regulatory intensity, related to state regulations and firm compliance for each of the 56 privately owned utilities in the study; 'the diversity of regulations and enforcement levels has resulted in varying degrees of compliance and different emission rates across plants' (ibid., p. 657). Their findings show that environmental regulation has caused an increase in production costs and an average decrease in productivity growth of 0.59 percentage points per annum over the period. After 1975, the date of full implementation of ambient air quality standards, this increased to an average per annum decrease in productivity growth of 0.88 percentage points. The technical change component of productivity growth was also negative in the early years of the sample but recovered in later years: 'importantly, the positive rates in the 1977-1979 period were sufficient to overcome the negative effect of environmental regulations in those years, thereby restoring positive productivity growth to the industry' (ibid., p. 671).

There are a number of problems with this study. Firstly, it only considers one element of compliance, input substitution. Other possible approaches are end-of-pipe abatement and cleaner production processes (Jorgenson and Wilcoxen, 1990). It does make reference to the possibility of flue gas desulphurisation, or scrubbers, but omits explicit consideration as 'with the exception of four firms, scrubbers do not play a large role in reducing firm-level emissions' (Gollop and Roberts, 1983, p. 664, n. 19). The data from these four firms is adjusted by using the reported design efficiencies (not actual efficiencies) of the installed technology. It seems likely that the importance of more integrated pollution control strategies has increased with time. Gollop and Roberts note that, although only seven of the sample of 56 had scrubbers in 1975, this had increased to 47 by 1980. This suggests a problem with the choice of time period. Gollop and Roberts defend their choice as appropriate, 'the sample years not only span the period when environmental regulations became increasingly important but they also represent a complete business cycle' (ibid., p. 661). But the statistics on increased scrubber installation would suggest that firm compliance activities have a longer time span than the business cycle, and that the importance of scrubber technology could only be ignored because of the choice of time period, early in the industry's compliance experience. The study considers technical change and environmental regulations as separate effects but ignores the possibility that environmental regulation and technical change effects could be interrelated, particularly as experience of compliance grows.

Grey (1987) considers the effect of environmental and health and safety regulations on the growth of US productivity in 450 industries, 1958 to 1978. He looks at the effect of regulation on total factor productivity, which is 'the contribution of all productive inputs to output growth' (ibid., p. 999). This measure has the advantage of not requiring an estimation of the production function. Grey identifies two effects on productivity growth: (a) the 'measurement effect' is where inputs actually used for compliance are included in the calculation of productive inputs, thus understating true productivity, (b) the 'real effect' is where regulations 'impose constraints on the firm's choice of production processes, make it harder to take advantage of new innovations, cause firms to lower new investment by increasing uncertainty, or otherwise reduce the productivity of other (non-compliance) inputs' (ibid., p. 999). Grey measures the total factor productivity at industry level, using reported pollution abatement costs as a proxy for regulation intensity. He finds a total (environmental and health and safety regulations) impact of an average fall in annual productivity growth of 0.44 percentage points. However he finds that environmental regulation contributes only 0.17 percentage points of the total of 0.44 percentage points and that this is not statistically significant. Furthermore the impact of environmental regulation is limited to measurement effect only, 'with no real effect on the productivity of inputs actually used in production' (ibid., p. 1005).

Barbera and McConnell (1990) also estimate total factor productivity, but for a restricted range of five of the most heavily regulated US industries, for the period 1960 to 1980. They divide productivity into direct, regulation effects, 'the diversion of resources towards abatement capital', indirect, regulation effects, where 'conventional inputs and production processes are changed in response to requirements' (ibid., p. 50), and technical change effects. The regulation effects are analogous to Grey's measurement and real effects, respectively. Barbera and McConnell stress that, although direct effects are, by definition, negative, they are not making any a priori assumptions about the sign of the indirect effects - a failing they ascribe to previous studies. In contrast to Grey, Barbera and McConnell find that there were indirect effects of environmental regulation in four of the five industries, suggesting that 'the abatement requirements change the optimal factor ratios as well as factor employment per unit of output' (ibid., p. 58). In general these indirect effects added to the negative direct effects on productivity. One exception was the chemical industry which demonstrated positive overall regulation effects between 1960 and 1970, perhaps because firms 'may have shifted to low-cost production methods and processes as a result of environmental regulation' (ibid., p. 59), although indirect effects had become negative by 1975. Overall, Barbera and McConnell find that between 0.12 and 0.43 percentage points of the decline in average annual productivity growth was due to environmental regulations. This study would appear to show a smaller impact than Grey's estimate of an average of 0.17 percentage points across 450 industries, which would appear to be accounted for by the focus on heavily-regulated industry

Jorgenson and Wilcoxen (1990) construct a general equilibrium model to simulate the long-run growth of the US economy and estimate the impact of regulation on GNP and competitiveness. The model covers a business sector of 35 industries, as well as government, household and rest-of-world sectors. Key parameters are estimated using empirical evidence and the model solves for equilibrium process over a number of time periods, allowing the tracing of adjustment processes. The base case model is the US economy with regulations in place, and the comparison case is one where regulation of industry and motor emissions are removed. The effect of industry regulation is incorporated by estimating pollution control operating and investment costs and removing them from industry costs; 'we assumed that investment in pollution control equipment provides no benefits to the producer other than satisfying environmental regulations' (ibid., p. 320). There is no consideration of any effect regulation might have on production costs and technology. Jorgenson and Wilcoxen find that the effect of all environmental regulations (industry operating costs, pollution equipment investment and motor car emissions) is a fall in GNP growth, over the period 1974-1985, of 0.191 percentage points, of which 0.14 percentage points is attributable to industry regulations.

Hetemaki (1995) is one of the few productivity studies to be carried out at plant level. He recognises the direct and indirect effects of productivity outlined by Barbera and

McConnell, and like them explicitly avoids any assumptions about the expected sign of effects, but restricts his estimates to the net overall productivity effects. His study considers the impact of water regulations on the productivity of the Finnish paper industry, based on a set of panel data covering nine plants between 1972 and 1990. Hetemaki uses an output distance function to determine net productivity effects by estimating the shadow price of emitted pollutant. His approach is explicitly neoclassical but has the advantage that 'no maintained behavioural hypothesis (cost minimisation or profit/revenue maximisation) is required' (ibid., p. 199). This approach avoids the problems of modelling regulations. Instead it calculates shadow prices for production outputs including emitted pollutants; these 'reflect the trade-off between desirable and undesirable outputs at the actual mix of outputs' (ibid., p. 203). His findings are that the shadow prices of all pollutants are small but positive, suggesting that 'the environmental regulations enhance the revenues of the plants', and 'productivity improvements have emerged as the serendipitous by-product of waste-water reduction' (ibid., p. 220). Hetemaki attributes this to the effect of the regulation in either stimulating learning effects in internal process changes or in increasing capital modernisation. He cites anecdotal evidence from a plant manager about 'unanticipated improvements in production efficiency' (ibid., p. 220).

Limitations of the Neoclassical Approach

The overall conclusion of these neoclassical models of innovation under environmental regulation is that market-incentives instruments offer better incentives to firms to innovate than direct standards regulation. However it is clear that the findings rely on the strong underlying assumptions. The models present a limited view of innovation by firms, one that assumes away many of the key features of environmental innovation in the real world.

> The efficiency argument is the most often put and the least often examined. It is easy to show the greater efficiency of a tax over a regulatory standard in theory, where markets are perfectly competitive and firms – but not the regulators! – have perfect information. But in the real world the arguments often do not hold (Jacobs, 1995, p. 57).

Downing and White (1986) show that the optimality of incentive-based regulations depend on the regulator being able to adjust smoothly to changed marginal conditions. In the real world the regulator is often constrained by lack of information or political inertia. The results of the Biglaiser and Horowitz (1995) model are sensitive to the assumption of constant marginal damages (Jaffe et al., 2000). All the models assume that the pollution control technology can be modelled as achieving a constant reduction in the marginal abatement curve at every level, whereas technologies more usually have a specific range of efficiency. The idea that environmental innovation may have a positive impact on production is also ignored, allowing no consideration of the choice between control through end-of-pipe and integrated cleaner technologies. For example, in establishing an estimated learning curve, Wiersma assumes that learning effects calculated in a production environment are not different to learning effects in compliance, but does not admit the possibility that production costs may themselves be affected by the learning effects associated with compliance experience.

Empirical studies have not had much success in establishing any relationship, positive or negative, between regulation and competitiveness. However it is interesting that the only two studies that do demonstrate some positive effects of regulation on productivity (Barbera and McConnell, 1990; Hetemaki, 1995) are those that explicitly avoid making a priori assumptions about the negative impact of environmental regulation. It is interesting that Hetemaki's (1995) was the only study conducted at plant level. Tobey (1990) estimates compliance costs at no more than three percent of total firm costs, even in the most regulated industries but one Irish pharmaceutical plant estimated their compliance costs at 30 percent of operating costs (Hilliard, 1994). This would suggest that a firm or industry level study is unlikely to pick up the impact of regulation as any influence is likely to be masked by the larger factors that operate at that level of analysis. The most appropriate level of analysis for research into the relationship between regulation and productivity is at the level of the plant.

Kemp (1997) identifies serious limitations in the neoclassical approach: simplistic modelling of pollution technology; neglect of supplier firms as a source of innovation; failure to consider policy-innovation feedback effects (policy decisions are based on available technology; technology investment decision are based on current policy); and the assumption that regulators can implement optimal policy without constraint. This leads him to conclude that 'there is no realistic account of the innovation process and technical change. The practical usefulness of the models as tools for public policy is believed to be limited' (Kemp, 1997, p. 49). The ability of neoclassical economics to handle the key features of innovation has been criticised by many economists. These models of innovation under environmental regulation rely on the neoclassical theory of the firm, and hence suffer from the same limitations.

> The ideal type of neoclassical environmental economics relies on a standard model of economic behaviour in which firms and consumers maximise their profit in conditions approximating to perfect competition. It is on the basis of this model that neoclassical economists are often to be found arguing that financial incentives are the most efficient means of achieving environmental goals. But this is not a model which conforms to the real world. As elsewhere it ignores the ways in which lack of information, time constraints and institutions and culture affect behaviour. These factors can severely constrain the value of the neoclassical prescription (Jacobs, 1994, p. 82).

The central tenets of the neoclassical approach, as identified above (methodological individualism, rational optimisation and the efficiency of markets) are incompatible with the key features of the innovative process. This is characterised by O'Sullivan (2000) as being a cumulative learning process requiring a collective learning effort and with an inherently uncertain outcome. She identifies how the neoclassical focus on market exchange requires the assumption of an innovation process that is instead (i) reversible not developmental – where the allocation of resources today has no impact on decisions tomorrow; (ii) individual – with no consideration of organisational coordination problems; (iii) optimal – implying a choice between given outcomes. Jaffe, Newell and Stavins (2000), in a survey of the economic literature appropriate for exploring technological change and the environment, implicitly acknowledge that theoretical models in current use in neoclassical environmental economics say 'little about what generates technical change' (ibid, p. 9). They point out that many of the neoclassical models outlined above could more easily be described as models of diffusion and adoption, given the exogenous determination of technology that is assumed. The authors refer to more sophisticated neoclassical models of innovation with endogenous technical change, such as those developed by Romer (1990, 1994). These models have not been taken up by environmental economists and their usefulness for exploring questions relating to technical change and environmental quality remain hypothetical and hampered by 'the difficulty of linking ... to the microeconomic foundations of technological innovation and diffusion' (ibid, p. 21). Jaffe et al argue that evolutionary economics may be a more appropriate tool for the analysis of innovation than the neoclassical model, given that 'the large uncertainties surrounding the outcomes of R&D investments make it very difficult for firms to make optimising R&D decisions' (ibid, p. 12). They recognise that relinquishing the assumption of profit-maximisation means that

> a logical consequence of the evolutionary model is that it cannot be presumed that the imposition of a new external constraint (for example, a new environmental rule) necessarily reduces profits. There is at least the theoretical possibility that the imposition of such a constraint could be an event that forces a satisficing firm to rethink its strategy, with the possible outcome being the discovery of a new way of operating that is actually more profitable for the firm' (Jaffe et al., 2000, p. 13).

However, while recognising that 'R&D has important characteristics that distinguish it from investment in equipment or other intangible assets' (ibid, p. 10) that justify the relaxation of profit-maximisation, the authors avoid addressing any of the fundamental differences between the evolutionary and neoclassical characterisations of innovation discussed above. These differences mean that the evolutionary and neoclassical schools are more fundamentally divergent than is accounted for by the authors' description of 'multiple methodological viewpoints' (ibid, p.66).

There has been little research on environmental issues carried out within the evolutionary framework (Jacobs, 1994). However, the analysis of technical change by firms in response to environmental regulation may be as much a question for industrial economics as it is for environmental economics. Theoretical and empirical research about the impact of environmental regulation on industrial performance has largely been the preserve of environmental economists, with only a small contribution from industrial economics (Schmalansee, 1993), but this research has not been extensive or conclusive (Jaffe et al., 1995). It is argued in this thesis that evolutionary economics, as a developed and robust alternative that overcomes the identified limitations of the neoclassical approach to analysis of innovation, offers an appropriate analysis of the question of regulation and cleaner technology adoption. The research presented here, using this framework will contribute to meeting Kemp's call for a 'realistic account of the innovation process and technical change' that can be of practical use as 'tools for public policy' (Kemp, 1997, p. 49).

Alternative Environmental Economics

Evolutionary economics is an alternative to the neoclassical treatment of technical change. Other economists have developed alternative approaches that address perceived problems with the metaphysical foundations of neoclassical environmental economics. The most important of these is the work of Georgescu-Roegen which aims to develop an economy-environment model consistent with the laws of thermodynamics. These laws are: (i) 'the energy of the universe is constant'; (ii) 'the entropy of the universe tends to a maximum' (Georgescu-Roegen, 1986, p. 3). Acceptance of these laws implies a distinctly different ontology to the neoclassical. The law that the universe moves from a state of low entropy, with freely available energy and matter, towards a high entropy state, characterised by dissipated energy and matter, means explicit acceptance of time's arrow (England, 1994), that is, of the direction and irreversibility of time. The processes of neoclassical economics are ahistorical, being focused on the development of universal, immanent laws of economic relationships, that is, time's cycle (Gould, 1986). It requires recognition of the fact that the economic system is not a closed system, as neoclassical economics assumes, but rather an open system that is embedded in the ecosystem and only sustainable with inflows of material and energy and outflows of waste (Ruth, 1993).

This conception takes explicit account of the 'ecologically bounded possibilities for using natural resources' (Dretz and van der Straaten, 1992, p. 39).

On a physical level the laws of thermodynamics set ultimate limits on economic growth. Matter and energy can be neither created nor destroyed, and the degradation and dissipation of the existing matter and energy is 'an unavoidable consequence of their use' (England, 1994, p. 201). This process implies a change in the environment which is providing the material and energy inputs to the economic system, and so the economic system evolves in a way that is not just quantitative (as neoclassical economics would hold) but also qualitative. The dissipation of available matter and energy, and the irreversible nature of this process, mean that, although technical change may increase the efficiency of transformation processes, there is no escaping the ultimate scarcity of natural resources.

> The mainstream view is that there is only superficial scarcity, because everything is obtainable if one is prepared to invest the necessary capital in labour and equipment. The much stronger thesis that technological innovations can always do away with scarcity of any item has become the first article of economic faith of virtually all economists (Georgescu-Roegen, 1986, p. 11).

Another school of thought goes beyond criticism of neoclassical economics for its neglect of economy-environment interactions and explicitly blames the prevalence and influence of neoclassical economic thought for the extent of environmental degradation. Daly and Cobb (1989) argue that economic abstractions and atomistic thinking, when mistakenly applied to the real world, have led to a neglect of 'the bonds of sympathy and human community' and 'the bonds of biophysical community' (ibid., p.37): 'the use of the model influences actual behaviour away from community-regarding paths towards selfish ones' (ibid., p.92). This is an epistemological attack, claiming that neoclassical economics, through its narrow view of how we know the environment, denies essential elements. They point to the classification of serious environmental problems as externalities or 'ad hoc corrections introduced to save appearances': 'when the vital issues (e.g. the capacity of the earth to support life) have to be classed as externalities, it is time to restructure basic concepts and start with a different set of abstractions that can embrace what is previously external' (ibid., p.92). They criticise the idea that technical progress will lead to the removal of environmental constraints. Like Georgescu-Roegen, they point to the implications of the laws of thermodynamics. They suggest that new knowledge may just as easily reveal new limits as push back existing constraints. Even if new technology does offer increased resource efficiency it will still rely on the existence of resources to operate; 'the constricted entry point of knowledge into the physical economy is through the availability of low-entropy resources' (ibid., p.199).

Söderbaum (1990) also considers that 'thinking habits in relation to economics can be listed among the factors potentially contributing to environmental problems' (ibid., p.481). To overcome methodological shortcomings in neoclassical economics he advocates 'paradigmatic pluralism' in which environmental problems are recognised as 'multidimensional and multidisciplinary' (ibid., p.483). In his view neoclassical economists approach their characterisation of environmental issues in a way that allows them to be analysed with neoclassical tools, without recognising that 'there is a mutual dependence between the person looking at some particular problem area and "what is seen"' (ibid., p. 484). 'Neoclassical economics reflects a very specific philosophy in its arguments about marginal monetary costs and benefits... This philosophy is one of monetary reductionism... Cost benefit analysis also implies that the analyst can approach the issue of values and ethics in society with scientific objectivity' (ibid., p. 487). The neoclassical view, even within environmental economics, continues to focus on economic growth, despite the fact that the nature of environmental problems would suggest that this is a limited view. Söderbaum is doubtful of the value of environmental economics; 'as I see it, neoclassical environmental economists are wasting scarce intellectual and financial resources by trying to do what is impossible or not meaningful' (ibid., p. 490).

Conclusion

Neoclassical environmental economics can be criticised on two levels. On a general level the neoclassical economics research programme can be criticised for its mechanistic characterisation of environment-economy interactions and its willingness to separate consideration of the environmental constraints on economic activity into a sub-discipline. At a more specific level it can be criticised on the grounds of the inadequacy of its models to analyse the impact of regulation on firm behaviour.

The central result of the neoclassical theoretical models of firm regulation is that regulation will always increase costs, and that market-based incentives are the least-cost type of regulation. This finding has meant that there is little interest in exploring the impact of innovation on environmental performance, with the result that 'although there are strong theoretical arguments against the efficiency or cost-effectiveness of command-and-control technology standards, there has been relatively little empirical research on the actual effects of technology-mandates on the rate and direction of technology diffusion.' (Jaffe et al., 2000, p. 62).

The exclusive focus on the superiority of market-based instruments has meant that the potential for other types of regulation to induce technical change with economic and environmental benefits is assumed away. This emphasis is questioned by Jacobs:

> *All* tools that change the behaviour of firms and consumers are economic, since economics is the study of the behaviour of these agents. Behaviour is changed as much by regulation as by taxes and subsidies: if economists do not study how, they do not understand what is going on in the economy. ... since regulations and market-based instruments are often presented as alternatives, it seems odd that economists show so little interest in how the many different kinds of regulation do and could work – to the point of not calling them economic instruments at all (Jacobs, 1995, p. 55).

The neoclassical models and empirical studies presented above have made crucial simplifications and abstractions that have denied the key characteristics of the issue of innovation in environmental compliance. The models of innovation do not explore the relationship between research and innovation but assume that research results in the development of new technology with known abatement costs. It is clear that environmental economics faces severe shortcomings when it comes to analysing the adjustment of industry behaviour to environmental regulation.

At least one group of economists working within the neoclassical tradition (Jaffe et al., 2000) have recognised that the emphasis on rational optimisation may prevent a useful analysis of technical change. These economists have identified evolutionary economics as an alternative approach, although there has been little research on environmental issues carried out within the evolutionary framework (Jacobs, 1994). This thesis includes a presentation of the evolutionary theory of the firm and an exploration of its potential for application to the environmental regulation of industry.[28] In this chapter I have argued that the underlying assumptions of neoclassical environmental economics make it an unsuitable theory to apply to questions of technical change. This argument is explored further in the following chapter. The debate between an industrial economist who challenges the profit-maximising view of the firm and neoclassical environmental economists shows very clearly the difficulties in the orthodox position, but also the inherent problems in developing an alternative theory of innovation.

[28] Chapter five.

4: The Impact of Environmental Regulation - An Alternative View

Environmental Regulation and Industry - A New Approach?

The dichotomy between environmental protection and economic growth has recently been challenged by Michael Porter who claims that 'the new paradigm of international competitiveness is a dynamic one, based on innovation' (Porter and van der Linde, 1995b, p.97) and that 'environmental standards can trigger innovation' (ibid., p.98) leading to both social and private gains.

This argument, made by an influential industrial economist, has mounted a significant challenge to the prevailing orthodoxy put forward by environmental economists, in both theoretical and empirical research, namely that environmental regulation will *always* increase costs for complying firms and that attention should be focused on weighing of compliance costs against the social benefits of environmental protection.

Porter's position, which has come to be known as the Porter hypothesis (Oates et al., 1993), originated in a brief outline given in 1991 (Porter, 1991, p.96). This paper is closely related to the concerns of Porter's research in *The Competitive Advantage of Nations* (Porter, 1990), where he found that 'nations with the most rigorous requirements often lead in exports of affected products' (Porter, 1991, p.96). This is contingent upon the requirements stimulating innovation in industry that is valued by the global market. Porter argues that there is a causal link between stringent environmental regulations and export leadership, citing German prowess in air-pollution technology.

He extends the argument beyond the environmental technology industry, claiming that 'properly constructed regulatory standards, which aim at outcomes and not methods, will encourage companies to re-engineer their technology' (ibid., p.96), and that 'strict product regulations can also prod companies into innovating to produce less polluting or more resource-efficient products that will be highly valued internationally' (ibid., p.96). Given the global trend of increased environmental protection, there are early mover advantages for the industry of any country that anticipates this trend in their legislation, allowing nations to translate improved domestic resource productivity into increased international competitiveness.

This chapter will present Porter's argument and show how it is rooted in a particular, non-neoclassical, conception of how firms compete. I will outline how this conception lies at the heart of the critique of Porter by environmental economists. I argue that Porter's significant contribution has been to change the type of questions asked about the impact of environmental regulation but that his research fails to demonstrate robust theoretical evidence of a positive relationship between environmental regulation and firm competitiveness. The reasons for this lie in the original research (Porter, 1990) in which Porter presents a richer and less abstracted conception of the firm but does so within the context of a model which stresses the primacy of the external environment[29] over internal firm characteristics as the factor of interest. This approach may be appropriate for a study of the determinants of national patterns of industrialisation but it proves problematic when Porter tries to extend his model to examine the impact of regulation on individual firms. However his work provides a signpost which suggests that the evolutionary theory of the firm has the potential both to resolve the failings of the neoclassical approach as identified by Porter and to answer the interesting questions raised by his own work.

The Resource Productivity Model

In addition to Porter's original hypothesis that regulation can stimulate innovation responses that anticipate world demand conditions, Porter's argument has evolved significantly through research specifically in the area of environmental regulation and competitiveness. He has developed his model to incorporate 'eco-efficiency', that is, the *particular* nature of environmental regulation as a tool for achieving increased productivity. A more recent statement of his position is:

> The prevailing view is that there is an inherent and fixed trade-off: ecology versus the economy...Properly designed environmental standards can trigger innovations that lower the total cost of a product or

[29] Environment is used here not in the sense of the natural environment, but in the more general sense of the institutional environment faced by the firm.

> improve its value. Such innovations allow companies to use a range of inputs more productively - from raw materials to energy to labour - thus offsetting the costs of improving environmental impact and ending the stalemate. Ultimately this enhanced *resource productivity* makes companies more competitive, not less (Porter and van der Linde, 1995a, p.120).

Resource productivity is the element that links the goals of environmental protection with the goals of dynamic competition: 'at the level of resource productivity, environmental improvement and competitiveness come together' (Porter and van der Linde, 1995b, p.106). Pollution is 'a manifestation of economic waste' (ibid., p.105) of many forms including not only inefficient input use[30] but also activities that add no value, such as waste treatment, and costs borne by customers such as disposal and inefficient energy use. Thus physical waste 'can carry important information about flaws in product design or the production process' (ibid., p.106). Pollution prevention can become a tool for achieving increased efficiency and can support the firm's strategy in the face of the demands of dynamic competition for continuous technical change and innovation at both product and production levels. This results in improved productivity, following Porter's (1990) definition of productivity as determined by both the efficiency with which inputs are transformed into output and by the value of that output.

In the 1970s environmental strategy was limited to end-of pipe compliance; the 1980s saw a move to integrated pollution-prevention. Porter and van der Linde see this as a process where, as a firm's experience of environmental compliance grows and the associated knowledge and skills become internalised, so their environmental management strategy will become increasingly integrated into their general management strategy. Porter and van der Linde predict further evolution into the resource productivity model where environmental protection is not just integrated into company practice but functions as a strategy for promoting continuous innovation. They make the comparison with the adoption of total quality management

[30] As discussed in the previous chapter, an upper limit is placed on the efficiency of input transformation by the 2nd Law of Thermodynamics, which states that any transformation of energy or matter involves some unavoidable dissipation or waste (Ruth, 1993).

techniques (TQM). Before the 1980s, US firms treated quality as an expensive add-on and saw a quality-cost trade-off. Awareness then grew of techniques used in Japan where by building quality techniques into their production activity firms achieve improved quality and reduced costs. In fact TQM quality audits search organisational processes for inefficiency, known as *muda,* the Japanese for waste (Womack and Daniel, 1996).

Porter's hypothesis has brought him into direct conflict with orthodox environmental economists who dispute his arguments. The dispute centres on fundamental differences in assumptions about how firms innovate and compete. Therefore, before turning to a discussion of the debate between Porter and environmental economists, it is instructive to examine more closely Porter's assumptions about the nature of the firm.

Porter's Conception of the Firm

Porter and van der Linde see the mechanism by which firms benefit from regulation as follows. Firms are inhibited from developing successful environmental innovations. Firstly there are limits to their range of action in any given period; that is, they cannot explore all potential innovation opportunities at once. Furthermore their choice of opportunities to investigate will be influenced by their inexperience in dealing with new areas. This will be reinforced by the fact that the firm is a product of past experience and this organisational inertia militates against radical change. Environmental regulation acts as a trigger which (i) overcomes the problem of inertia by mandating a response; (ii) directs the firm's attention to the potential benefits of resource productivity; (iii) encourages the firm to innovate in an area which is increasingly valued by consumers.

Porter's argument is located within the framework of his broader research in *The Competitive Advantage of Nations* (Porter, 1990) on the implications of a global shift to a new form of competition requiring continuing innovation by firms to maintain their competitive position. Porter's view of competition and firm behaviour is much richer and less abstract than the mainstream neoclassical view. He considers that as modern industry has come to be characterised by high-skill, technology and knowledge-intensity, so the assumptions of neoclassical theory have meant that it is increasingly unable to analyse global competition and competitive advantage. 'The standard theory assumes that there are no economies of scale, that technologies everywhere are identical, that products are undifferentiated, and that the pool of national factors is fixed... All these assumptions bear little relation, in most industries, to actual competition' (ibid., p. 12). He criticises the model of fixed productivity and mobile factors: 'in reality, however, innovation can often boost the productivity of the resources employed in an industry much more than the gains from reallocating them' (ibid., p. 116).

Porter takes an explicitly Schumpeterian view of competition,[31] that is, competition as 'dynamic and evolving' (ibid., p. 20) and requiring continuous innovation as firms compete on the basis of the introduction of new products, process technology and organisational structures. 'Instead of simply maximising within fixed constraints, the question is how firms can gain competitive advantage from changing the constraints' (ibid., p. 21). Successful competitive positions are sustained on the basis of durable, hard to imitate, advantages in technology, product differentiation, brand reputation and customer relations. Building these advantages requires 'more advanced skills and capabilities such as specialised and highly trained personnel, internal technical capability, and, often, close relationships with leading customers' (ibid., p. 50). In particular the ability to innovate is an advantage that is crucially dependent on learning: 'it results from organisational learning as much as from formal R&D. It always involves investment in developing skills and knowledge' (ibid., p. 45).

Porter recognises that acquiring these firm-specific advantages 'depends on a history of sustained and cumulative investment in physical factors and specialised and often risky learning, research and development, or marketing' (ibid., p. 50). He considers the risk of rigidity associated with path-dependant, cumulative assets; 'the ability to

[31] See chapter five for a fuller exploration of Schumpeter's view of competition.

modify strategy is also blocked by the fact that a company's past strategy becomes embodied in skills, organisational arrangements, specialised factors, and a reputation that may be inconsistent with a new one' (ibid., p. 52). This is one of the major advantages that a national environment can give to a firm or cluster - tackling inertia by forcing companies to innovate. 'Innovation is disruptive... Innovation to offset selective weaknesses is more likely than innovation to exploit strengths. Selective disadvantages create visible bottlenecks, obvious threats, and clear targets for improving competitive positions. They prod or force a nation's firms into new solutions' (ibid., p. 83).

Porter considers that 'the pressure to change is more often environmental than internal' (ibid., p. 52) and such pressures may include elements of the "diamond" (such as strong competition, demand conditions and resource scarcity). The national environment influences innovation by the nature of the resources, physical and human, it offers to support innovative activity. Information that directs management attention and affects the direction of a firm's innovation efforts is provided by the nature of domestic demand, another element of the national environment. Another, indirect, pressure is government regulation which has influence through its effect on the "diamond", 'government... can hasten or raise the odds of gaining competitive advantage (and vice versa) but lacks the power to create advantage itself' (ibid., p. 128). One source of government influence is environmental regulation: 'stringent standards for... environmental impact contribute to creating and upgrading competitive advantage' (ibid., p. 647).

The Porter Hypothesis - as interpreted by environmental economists

Porter's provocative argument was met with two kinds of response: a warm reception from US policymakers (including Vice-President Gore (Gore, 1992) and the US Environmental Protection Agency (Oates et al., 1993)), and a defensive, sceptical response from neoclassical environmental economists. The original statement of Porter's argument was in a brief, one page editorial in *Scientific American* (1991)[32]. A

[32] In *The Competitive Advantage of Nations* (1990, p. 647) Porter discussed the importance of the positive affect of all regulation, including brief reference to environmental regulation.

fuller articulation, with supporting evidence, did not appear until 1995 (Porter and van der Linde, 1995a; Porter and van der Linde, 1995b). In the intervening period a series of papers, mainly connected to the influential US environmental economics research institute, Resources for the Future, attempted, in the absence of any detailed elaboration by Porter, to define his position and to refute and dismiss it using neoclassical economic theory.

Before turning to look at argument and counter-argument it is useful to examine how environmental economists[33] framed the debate. This reveals how environmental economists are constrained in the ways in which they approach the question of the regulation-innovation relationship by their underlying assumptions about the nature of competition and firm behaviour.

It is clear that the environmental economists neither mischaracterize the Porter hypothesis, nor reframe it to suit their own critical analysis, despite the lack of supporting theoretical or empirical evidence in Porter's 1991 article. Porter's argument is seen as the proposition that 'the tightening of US environmental standards will stimulate US growth' because 'rather than stifling productivity, environmental protection enhances competitiveness in the long run' (Palmer and Simpson, 1993, p.17). Jaffe et al. (1995) characterise Porter's position as being that regulation acts 'actually as a net *positive* force driving private firms and the economy as a whole to become more competitive in international markets' (ibid., p. 133). Oates et al. (1993) give a more precise definition of the hypothesis that is closer to Porter's own: 'the proposition that more stringent regulations of the right kind can lead to increased profitability for polluting firms' (ibid., p.5). Palmer et al. (1995) see the Porter hypothesis as 'the capacity of strong environmental regulation to induce

[33] There is an assumption here that these academics are in some way representative of the position of *all* mainstream environmental economists. Resources for the Future (RFF) is very much the home of US environmental economics: RFF scholars are responsible for some of the core textbooks (Baumol and Oates, 1979, 1988) as well as the most recent survey article in the Journal of Economic Literature (Cropper and Oates, 1992). Their own view is that 'we are widely – and even formally – credited with having brought into existence the scholarly subdiscipline of environmental and resource economists and applying it to emerging policy issues' (Portney, 1996, p.2). Furthermore it can be seen from the survey of environmental economics in chapter three that the position taken by the RFF economists is consonant with general neoclassical environmental economics research on the regulation-competitiveness relationship.

innovation' (ibid., p.119) or, more baldly, 'environmental protection, properly pursued, often presents a free or even a paid, lunch' (ibid., p.120).

The problem faced by these environmental economists in responding to the Porter hypothesis is that because of the brevity of the original paper (Porter, 1991) they have to infer Porter's theoretical position before they can argue against it. In these papers the environmental economists explore the validity of the Porter hypothesis by firstly generating possible arguments where the hypothesis might be said to hold. The ways in which these economists conceive of the regulation-innovation relationship and the Porter hypothesis illustrate the constraining influence of their underlying assumptions. They choose arguments that have already been subject to debate within economics and that are easily refuted, often by recourse to the assumption of profit-maximising firms. These arguments are:

(i) Regulation could improve competitiveness where firms operate inside their efficiency frontier because they have failed to recognise profitable innovations in environmental compliance (Palmer and Simpson, 1993; Oates et al., 1993; Jaffe et al., 1995).
It is argued that this is consistent with profit-maximising behaviour, given opportunity costs, information costs and uncertainty. What may appear to be inefficiency or 'slack' could be rational behaviour: 'since resources are scarce, even if more stringent environmental regulation *does* prompt the firm to uncover inefficiencies in the production process, the resulting savings *may* come at the expense of even greater savings elsewhere' (Oates et al., 1993, p. 19). Therefore, for the profit-maximising firm 'on occasion, it may be perfectly reasonable, logical and efficient to pass up opportunities for developing environmental technologies' (Palmer and Simpson, 1993, p. 18).

Furthermore, were firms systematically overlooking profitable innovations this would be corrected by the market for capital control: 'failure to minimise production costs would be sustainable only if there were also information barriers or other imperfections in capital markets that prevent efficient managers from identifying the existing inefficiency and taking over the firm' (ibid., p. 19).

(ii) Regulation could improve competitiveness where the behaviour of foreign competitors can be influenced by strategic standard setting, leading the US to improve its international trade position (Palmer and Simpson, 1993; Oates et al., 1993; Jaffe et al., 1995).
This argument is based on the strategic trade theory developed by Krugman (1987). The model has been shown to be highly dependent on the initial conditions, with the choice of strategy to achieve the desired outcome dependent on whether competition is Cournot (output is the decision variable) or Bertrand (price is the decision variable). It can therefore be easily dismissed by the environmental economists, being less of a practical policy tool than a theoretical curiosity: 'while it is possible...to get "pro-Porter" results from models that incorporate strategic behaviour, it is our sense...that such results are special cases' (Oates et al., 1993, p. 12).

(iii) Regulation could improve competitiveness where the abatement technology industry will benefit both from increased demand and from innovation induced by the increased use and experience of the technology (Oates et al., 1993; Jaffe et al., 1995). This is dismissed as an unlikely situation where structural adjustment in response to regulation results in the gains made in the abatement technology industry outweighing the cost to the rest of industry. 'Tougher environmental regulations, in short will almost surely lead to an expansion of the abatement technology industry and an intensification of its R&D efforts'. However 'while all this may be true, trade in abatement technology cannot loom very large in the overall trade picture' and there is evidence that 'although the US is a major exporter of pollution control equipment, these exports account for less than one-half of one percent of total US merchandise exports' (Oates et al., 1993, p. 15).

(iv) Regulation could improve competitiveness where firms may be able to benefit, at the expense of other firms, from a changed regulatory environment, either because they face lower compliance charges or because they gain early-mover advantages in meeting regulation-induced demand.

Jaffe et al. (1995) dismiss this as a situation where adjustment to regulation results in winners and losers, but it is unlikely that the gains to winners will outweigh the overall cost of compliance.

It can be seen from this list that no attempt has been made to engage with Porter's conception of firm behaviour and competition. These papers focus on the propositions in this essay without reference to the original research in *The Competitive Advantage of Nations*. Ignoring the clue given by the dismissive reference to analysis that takes 'a narrow view of the sources of prosperity and a static view of competition' (Porter, 1991, p.96), they are only able to conceive of approaches from within mainstream economics, approaches that do not challenge the assumption of profit-maximisation and can be easily refuted.

The Core Debate

The core of the debate is contained in a pair of papers in the *Journal of Economic Perspectives*. Porter and van der Linde (1995b) presented the first detailed defence of their position and Palmer et al. (1995) responded with their theoretical and methodological objections. The focus in these papers is now clearly on the key question of the relationship between regulation and innovation within the firm. Environmental economists dispute the regulation-innovation link for three main reasons, all rooted in a neoclassical, profit-maximising conception of the firm. Counter arguments by Porter and van der Linde are located in their non-neoclassical conception of the firm. The main counter arguments are as follows:

(a) If opportunities to combine environmental protection with increased profits did exist, firms would exploit these opportunities without requiring regulatory inducement.

Porter and van der Linde argue on the contrary that 'rather than attempting to innovate in every direction at once, firms in fact make choices based on how they perceive their competitive situation and the world around them. In such a world, regulation can be an important influence on the direction of innovation' (1995b, p.99).

(b) Given costs of information and uncertainty, firms that do not exploit innovative opportunities may be making an efficient choice.

However, it is precisely the role of environmental regulation in providing information signals about potentially profitable innovations in environmental compliance and in reducing uncertainty about the value of such an investment that Porter and van der Linde see as one of the ways that regulation can promote a positive effect. 'Companies are still inexperienced in measuring their discharges, understanding the complete costs of full utilisation of resources and toxicity, and conceiving new approaches to minimise discharges or eliminate hazardous substances. Regulation rivets attention on this area of potential innovation' (ibid., p.99).

(c) Firms may be aware of environmental innovations and still choose not to pursue them because of more profitable opportunities in other areas.

This is a view of profit-maximising firms with perfect knowledge. Porter and van der Linde do not accept that environmental innovations go unexplored because they have been weighed in the balance and found wanting. Instead they see that (i) 'companies have numerous avenues for technological improvement, and limited attention' (ibid., p.99), and (ii) 'companies are still inexperienced in dealing creatively with environmental issues. The environment has not been a principal area of corporate or technological emphasis, and knowledge about environmental impacts is still rudimentary in many firms and industries' (ibid., p.99).

Other objections to the Porter hypothesis centre on the nature of regulation. Environmental economists question why regulations should succeed in recognising profitable innovations where firms have failed. This is answered by Porter and van der Linde's assertion that it is the *form* of regulations that is important in promoting innovation, and that the right form is for regulations to be as flexible as possible and to 'create maximum opportunities for innovation by letting industries discover how to solve their own problems' (1995a, p.129). Environmental economists dispute the positive impact of environmental regulation on competitiveness, arguing that, even if regulation does induce increased research in environmental compliance, there is no theoretical evidence to link this research with realised gains in profitability. Porter and van der Linde's theory holds that the particular relationship between physical and economic waste provides environmental regulation with the potential to act as a tool for inducing profitable innovation and increasing resource productivity throughout the production process.

Irreconcilable Differences

As the debate has developed the position of the environmental economists has undergone subtle shifts. By Palmer et al. (1995) they have begun to engage more directly with the substance of Porter's thesis, that is, the role of regulation as a direct stimulus to profitable innovation within the firm. Palmer et al. (1995) even begin their paper with a peace-offering, a list of points where they are in agreement with Porter and van der Linde: they believe in the superiority of incentive-based regulations that do not lock firms into particular technologies but allow them to devise their own compliance strategies; they accept that technical change can lower the estimated (static) costs of compliance; and they acknowledge that regulation can lead to innovations, cost-savings and quality improvements. Porter and van der Linde (1995b) make some concessions also: they allow that innovations may not be enough to cancel out the full costs of compliance; they accept that regulations will not induce innovations in all firms; and they concede that some high toxicity pollutants will always require inflexible, emission-standard regulation. However when it comes to making concessions on theoretical ground, hard-line positions are adopted. Palmer et al. (1995) recognise that Porter and van der Linde's argument rests on adopting a dynamic approach, but persist in analysing the theory using a static model of firm behaviour, even though they recognise that their model is 'subject to precisely the sort of criticism that Porter and van der Linde level in their paper' (ibid., p.122).

The model (Oates et al., 1993; Palmer et al., 1995) is of a firm with two known technologies available to it, each with an associated marginal abatement cost function (MAC), which traces out the cost of treating each additional unit of polluting emissions. The more efficient technology, abating at a lower cost for any given level of emissions, can only be achieved by investment in R&D of a known amount.

This model is used to compare the firm's profits under two levels of regulation, with and without the technological innovation. The regulation is in the form of a pollution tax per unit of pollutant discharged (i.e. not abated by the firm). At the original level of pollution tax, P, the firm will operate at a level of abatement activity determined by equating P with its chosen MAC.[34] The firm can stay with its original technology and earn profits of Π_A, or invest in the new technology and earn Π_B, where it will abate a higher level of emissions. Π_A is assumed to be greater than Π_B, and therefore the firm will not voluntarily innovate.

Regulatory standards are increased, pushing the pollution tax to P', and moving the firm to a new level of abatement (and output). Again the firm can abate using the original activity, earning profits Π_C or move to the new technology, which will enable it to treat a higher level of pollution, and earn profits Π_D. The Porter hypothesis would suggest that increased standards would push the firm to innovate profitably:

i.e. $\Pi_D > \Pi_A$,

but in this model both options C and D leave the firm with lower profits than the original position A.

This is because, for any given technology, the increased pollution tax will necessarily mean reduced profits, therefore

$\Pi_A > \Pi_C$ - in the case of the existing technology

and $\Pi_B > \Pi_D$ - in the case of the new technology

Since, by assumption, $\Pi_A > \Pi_B$,

[34] Where MAC < P it is cheaper for the firm to abate its emissions, while where P < MAC the firm will pollute and pay the tax.

then, by transitivity, $\Pi_A > \Pi_B > \Pi_D$

and $\Pi_A > \Pi_D$

The result then is that the profit from the original position cannot be improved by investing in abatement technology innovation: $\Pi_A > \Pi_D$.

This result depends crucially on the assumption that the adoption of the new technology does not have any impact on the firm's other (non-compliance) production costs. It assumes that the level of regulation and not the form is enough to induce innovation. By construction it relies on assuming away the possibility of learning effects (by saying that, with given technology, increased regulation can only reduce profits) and the possibility of a profitable move from A to B. This model is similar to the models discussed in the previous chapter (especially Downing and White, 1986; Malueg, 1989) and suffers from the same problem of abstraction from the dynamic characteristics of innovation and learning.

Palmer et al. (1995) have a fundamental misconception of the underlying concepts of Porter's theoretical approach, claiming at one point that:-

> What distinguishes the Porter and van der Linde perspective from neoclassical environmental economics is *not* the 'static mindset' of the latter. It is two other presumptions. First, they see a private sector that systematically overlooks profitable opportunities for innovation. Second, and equally important, they envision a regulatory authority that is in a position to correct this 'market failure' (ibid., p.121).

Adherence to the conception of a profit-maximising firm appears to be so strong that Palmer et al. cannot or will not see that these 'presumptions' follow from a dynamic model. Firms which do not select optimal solutions from a known problem set but are instead dependent on internal experience, learning and development for the generation of solutions will 'systematically overlook profitable opportunities for innovation' (Palmer et al., 1995, p.121) if these opportunities lie in areas outside of the firm's previous experience. This gives a role to regulatory authorities, which do not have superior knowledge in the sense of legislating for the adoption of optimal solutions, but serve to supply an external stimulus that directs firms' attention to a new and potentially profitable area.

The defensive response of the environmental economists to moves into research that is traditionally their preserve has been strong. Porter's work has been characterised as 'astonishing' (Palmer et al., 1995, p.119), 'dubious' (Palmer and Simpson, 1993, p.21), 'revisionist' (ibid., p. 17) and as having 'a high ratio of speculation and anecdote to systematic evidence' (Jaffe et al., 1993, p.157). One of the reasons for the force of this response may be the implications that the Porter argument has for the continuing importance of their own research programme: 'If environmental regulations are essentially costless (or even carry a negative cost!), then it is unnecessary to justify and measure with care the presumed social benefits of environmental programmes' (Palmer et al., 1995, p.120). This is the reverse of the neoclassical environmental economists' position, which is that, having established the economic efficiency of market incentive based regulations (such as emissions taxes and permit trading), 'empirical studies on production technologies are becoming less relevant for policy' (Bovenberg, 1995, p.210).

However, research into empirical effects of regulation on competitiveness has not been a fruitful area for neoclassical environmental economists. A survey article, Jaffe et al. (1993), finds that this is not a popular area of enquiry, and that not only have the existing studies been unable to verify empirically their theoretical findings (thus failing to disprove the Porter hypothesis) but furthermore they doubt the ability of current research methods and available data to provide a definitive answer. Jaffe et al. (1993) have put forward the balanced view that acceptance of Porter's hypothesis must await convincing empirical evidence and that 'it is also important to recognise that we must go beyond tautological arguments that rest solely on the postulate of profit-maximisation' (ibid., p.157). They recognise problems with the environmental economics approach, finding that analysis at industry and nation level has suffered from problems with establishing the true cost of compliance and from the masking of the competitiveness-regulation relationship by larger effects. Jaffe et al. call for this to be remedied by research which is focused on plant level productivity effects and innovation triggers: 'an obvious gap in the literature surveyed herein is the lack of empirical evidence on the relationship between environmental regulation and innovation' (ibid., p.39). Porter and van der Linde argue that 'case studies are the only vehicle currently available to measure compliance costs and both direct and indirect innovation benefits' (1995b, p.101). They accept that Palmer et al. dispute the validity of using the case study approach; 'of course, a list of cases, however long, does not prove that companies can always innovate or substitute for careful empirical testing in a large cross-section of industries' (1995b, p.104, n.5), but maintain that there is no realistic alternative.

It would appear that some neoclassical environmental economists have responded to the points raised by Jaffe at al. and are conducting firm level, empirical research on the impact of regulation. Resources for the Future has begun work on at least ten different research projects on induced technological innovation since 1996, some involving case study, firm-level research. However, the problem remains that this research is rooted in neoclassical economics, and hence is constrained by the fundamental inability of neoclassical economics to encompass the crucial features of technological innovation.

This can be seen by looking at one such Resources for the Future project. Boyd (1998) takes a case study approach to explore the corporate evaluation of clean technology projects. His approach is to study three cases of technological innovations that failed to pass the corporate decision-making process with the aim of seeing whether the failure was due to (i) Porterian organisational barriers or (ii) rational profit-maximising decision-making.

The way the research project was set up reflects neoclassical economics' treatment of firm innovation as the profit-maximising based adoption of exogenously determined technology. For Boyd 'the term "organisation failure" connotes the existence of a correctable management strategy, accounting procedure, or financial methodology' (ibid., p. 37). His work offers analysis of the 'corporate rationale for rejecting, or delaying identifiable pollution prevention opportunities' (ibid., p. 37) and 'provides insight into the ways in which firms collect, process and act on information when making investment decisions' (ibid., p. 34). In Boyd's terms, if he found that firms were using incorrect techniques for assessing project profitability, and were therefore overlooking or rejecting profit-maximising projects, he would accept Porter's hypothesis that regulation may be necessary to stimulate clean technology adoption.

But the Porterian characterisation of organisational barriers, as discussed earlier (see section on 'Porter's Conception of the Firm', p. 62-64), is quite different to Boyd's approach. Porterian firms may not pursue profitable opportunities because inexperience and lack of knowledge of clean technology means that the firm is more likely to direct its limited attention to other, more familiar, areas of innovation. Organisational barriers relate to the path-dependent nature of the organisational learning and knowledge necessary to innovate in a given area; these organisational barriers do not relate to 'organisational weaknesses that make them unable to appreciate the financial benefits of P2 investments' (Boyd, 1998, p. ii). Boyd does not deal with how innovations are identified or with the factors affecting firms' abilities to generate new solutions. His criteria in selecting cases were that they involved a pollution prevention opportunity that was not pursued, subsequent to having been through a corporate financial analysis process. He takes examples of pollution prevention opportunities that were developed, but ultimately because of market or cost considerations were not implemented, and looks at the evaluation within the company that led to that decision. The first case is of a technology that was profitable, but not as profitable as an alternative clean technology that was adopted; the second case is of a profitable technology developed but not implemented as the business was sold; the third technology was embedded in a complex institutional system that mitigated against its adoption.

He concludes that 'the evidence contradicts the view that firms suffer from organisational weaknesses that make them unable to appreciate the financial benefits of P2 [pollution prevention] investments' (ibid., p. ii). 'The findings here run counter to the perception that firms are somehow failing to pursue win-win opportunities. Instead failure to pursue P2 is usually best explained by a project's lack of expected profitability' (ibid., p. 42). He also makes the more ambitious claim, despite his caveat that these cases 'cannot be used to draw broad policy or empirical conclusions' (ibid, p. 4), which is that his findings 'imply that there may be fewer high-return P2 opportunities than many believe' (ibid., p. 37). These cases present interesting opportunities to learn about the innovation process, but Boyd presents the challenge to firms purely in terms of the rational evaluation of the stream of costs and benefits from defined, complete projects. The research does not engage with Porter's argument that it is organisational resources/barriers at the level of knowledge and learning that affect a firm's ability to identify, generate and implement profitable cleaner technology projects. Boyd achieves nothing more than a demonstration of the truism that firms that make rational profit-maximising decisions will not adopt pollution prevention solutions that do not maximise profits.

In conclusion it would appear that neoclassical environmental economics has not been able to provide a definitive refutation of the Porter hypothesis. There has been little work done in this area,[35] and that work which has been carried out, despite being explicitly founded on the assumption that regulations increase costs for firms, has failed to demonstrate a significant negative impact on competitiveness. Some neoclassical economists (Oates et al., 1993; Jaffe et al., 1995; Jaffe and Palmer, 1997) have identified a possible solution in alternative research methods, looking for plant-level studies that examine the regulation-innovation relationship directly. However, as Boyd (1998) demonstrates, if this case-study work is based on the profit-maximising model of the firm, it will not answer the request put forward by Jaffe et al. (1993) 'to recognise that we must go beyond tautological arguments that rest solely on the postulate of profit-maximisation' (ibid., p.157). What we now need to consider is whether Porter and van der Linde have developed a convincing alternative approach.

[35] A point made by Jaffe et al. (1995) and borne out by a survey article of the discipline in the Journal of Economic Literature (Cropper and Oates, 1992) where in a 55 page article only one page was given to a discussion of 'measuring the costs of pollution control' (ibid., p. 721).

The Validity of the Porter Approach

The key question is whether Porter and van der Linde have made a theoretical contribution to research in this area. Have they developed a conceptual framework that will allow them to prove their argument that 'strict environmental regulation can be fully consistent with competitiveness' (1995b, p. 105) by demonstrating systematic regularities in the pattern of firm compliance? Or is their contribution restricted to raising interesting questions by presenting case study evidence that suggests 'there is reason to believe that companies can enjoy substantial innovation offsets by improving resource productivity throughout the value chain instead of through dealing with the manifestations of inefficiency like emissions and discharges' (ibid., p. 107). I believe that Porter and van der Linde are constrained in their attempt to develop a theoretical model by Porter's original framework. While this framework contains a *conception* of the firm that allows for innovation it does not contain a *theory* of the firm on which to build a theoretical model of environmental regulation as a stimulus to innovation in firms.

Porter and van der Linde's work is explicitly rooted in Porter's research for *The Competitive Advantage of Nations*. Porter's thesis is that the national environment faced by firms shapes the development of their competitive ability. The ability of the environment to promote the creation of competitive advantage depends on a system of four interrelated determinants, which Porter calls the "diamond". The four determinants are: factor conditions, such as skilled labour and infrastructure; sophisticated demand conditions in the home market; internationally competitive related and supporting industries; strong domestic rivalry and committed firm strategy.

When this environment fosters the development of abilities that lead to success in the global marketplace then the country's industry and the nation as a whole benefit. 'At the core of explaining national advantage in an industry must be the role of the home nation in stimulating competitive improvement and innovation... We must understand what it is about a national environment that overcomes the natural desire for stability and jars firms into advancing' (ibid., p. 70). Any understanding of national competitive advantage requires examination of why some national environments are superior at encouraging innovation. These differences are explored through an examination of industries and firms, and in particular the presence of clusters, that is, groups of internationally successful firms in the same or related industries with horizontal and vertical relationships to the other firms within the cluster. Porter finds that, although national environments are uniquely determined, there are patterns in the sources of competitive advantage that transcend national differences.

The 1991 statement of the Porter hypothesis is presented as a particular case of this general argument: environmental regulation can increase national competitiveness by stimulating firms to innovate in ways that are 'highly valued internationally' (1991, p. 96). One of the more effective criticisms of this argument is that while regulation may shift the focus of firms' R&D efforts towards environmental technology, there is nothing to suggest that this R&D 'is fundamentally different from other research' and will therefore lead to an improvement in competitiveness (Schmalensee, 1993, p. 27). In the later papers Porter and van der Linde (1995a, 1995b) counter this with an argument that it is the connection between physical and economic waste that makes innovation in the area of environmental performance especially effective in increasing overall productivity and competitiveness. This argument is known as the 'eco-efficiency' argument and did not originate with Porter and van der Linde.[36] Porter's hypothesis now becomes: (i) regulation encourages firms to explore and develop innovations in the area of environmental performance; (ii) innovations in environmental performance have the potential to increase resource productivity and reduce economic waste; (iii) if these innovations provide advantage in global competition then they will lead to increased national competitiveness.

This is the crux of the problem Porter and van der Linde have in moving beyond hypothesis and anecdotal evidence. Their argument depends on showing that there is a

[36] Early references include: OECD (1985), Ashford and Heaton (1983), INFORM (1985).

systematic relationship between environmental regulation and the innovation process within firms. However the theoretical base from which they are working, *The Competitive Advantage of Nations*, does not provide a developed theory of firm behaviour but instead focuses on the importance of national factors in explaining industry success. Although he claims that 'the behaviour of firms must become integral to a theory of national advantage' (Porter, 1990, p. 21), he explicitly acknowledges that this is not his focus in a footnote comparing his approach with that of the evolutionary economist Chandler:[37]

> Chandler's (forthcoming) historical research[38] on the rise of the multinational firm, which has proceeded in parallel to my own, stresses the development of internal skills and managerial capabilities[39] in the growth of successful international competitors. My stress is more on the environment surrounding firms, and how this influences the creation of strategy, skills, organisational arrangements, and success in particular fields (ibid., p. 786, n. 47).

The Importance of Organisational Capabilities

Porter is not the first researcher to consider environmental regulation as a stimulus to innovation, only the most prominent. Nicholas Ashford of MIT has been considering this question since the 1970s (Ashford and Heaton, 1979), and has used Klein's *Dynamic Economics* (1977) as a theoretical framework (Ashford and Heaton, 1983, Ashford, 1993). An examination of his work shows how deeper consideration of internal firm factors leads to a more subtle analysis than Porter's. However, I argue that Ashford's work, while it explicitly recognises the importance of unique, firm-specific processes, does not go far enough in developing and operationalising a model that accounts for the role of these processes in the regulation-innovation relationship.

Ashford and Heaton's argument has much in common with Porter and van der Linde, including the nature of competition and the rejection of the neoclassical approach:

[37] Chandler has identified himself as an evolutionary economist in Chandler, 1992a and 1992b.
[38] Chandler, 1990.
[39] Porter recognises the role capabilities may have in organisational inertia: 'the ability to modify strategy is also blocked by the fact that a company's past strategy becomes embodied in skills, organisational arrangements, specialised factors, and a reputation that may be inconsistent with a new one' (ibid., p. 52). However, he does not admit that capabilities have a role in enabling and shaping any move to a new strategy or that they offer a source of inimitable advantage.

> Klein's work concerns the concept of dynamic efficiency, as opposed to the static economic efficiency of the traditional economic theorists. In a situation of static efficiency, resources are used most effectively within a given set of alternatives. Dynamic efficiency, in contrast, implies a constantly shifting set of alternatives, particularly in the technological realm. Thus a dynamic economy, industry or firm is one which is flexible and which can respond effectively to a constantly changing external environment (Ashford and Heaton, 1983, p. 114).
>
> As Klein's work so persuasively suggests, a dynamic, innovative economy is built on a continual push towards change, based on stimuli that provide "negative feedback" to those firms that adhere to the status quo. Over the long run, regulation may provide one such important stimulus (ibid., p. 157).
>
> Static economic analysis suggests that, other things being equal, firms with reduced financial resources, fewer economies of scale, and higher compliance costs will be relatively penalised. A dynamic perspective (drawing on Klein's ideas) suggests, however, that a firm's technological base and market strategy, if relatively consistent with regulatory requirements, can work significantly to its competitive advantage (ibid., p. 127).

Ashford and Heaton use Klein's theory to develop a rich set of possible relationships between regulation and technical change in the chemical industry. They argue that regulation in respect of pre-market approval places higher static costs on new and small firms than on large, established firms and that research required by such regulation has benefits in increasing understanding of the product characteristics. However, regulation of existing products that is stringent and 'challenges the technological status quo' (ibid., p. 154) is likely to lead to the development of replacement products, often developed by newcomers. Regulations that require standards above that achievable with existing technology will promote innovation. Regulations mandating "best available technology" will promote diffusion of existing technology more than innovation. Finally, they argue that within any industrial segment[40] responses to regulations are largely determined by the general pattern of technical change within that segment to the point that the response within a given

[40] Industrial segment is a concept taken from Abernathy and Utterback (1978). A 'productive segment' is a subgroup within an industry using similar production technology, e.g. automobile engine manufacture is a segment within the automobile industry.

segment will be 'highly uniform' (ibid., p. 155). This suggests that in industrial segments where the product technology is still developing, these 'fluid' segments will respond to regulations with product change whereas more 'rigid' segments, where the product specification is fixed, will respond with process changes. However, responses characterised by 'technological novelty' are seen from both types of sector, rigid as well as fluid (ibid., p. 156).

Ashford and Heaton conclude that this:

> lends some support to the idea that regulation can change the overall character of innovation in rigid industries and that creative responses to regulation may occur where regulation precipitates crisis conditions for the industry. Again Klein's analysis of the conditions necessary for dynamic change seems to be supported by empirical findings (ibid., p. 156).

This last point shows up a weakness in Ashford and Heaton's work, where they fall short of their stated goals in one respect. They introduce their research by stressing the equal importance of considering the form of regulation, the nature of technology and the unique capabilities of firms.

> Effects at the industry or sector level are only one aspect of the regulation-innovation relationship. Perhaps, unfortunately, this level of analysis has been the primary focus of innovation research. Equally important, however, are *the differences in innovative capabilities among firms*. These differences stand out as strongly in the responses to regulation as they do in other competitive areas. To understand the differences in responses to regulation between firms and between different sectors of the chemical industry, a conceptual framework is needed to relate regulation to technological change (Ashford and Heaton 1983, p. 117, emphasis added).

The empirical research that they present clearly identifies that innovations are developed that cannot be accounted for either by the form of the regulation or by the general character of technical change within the segment. However, despite their stated aims, they do not go beyond a sector-specific level of analysis to consider the firm-specific processes that gave rise to these innovations. The reason for this gap is that the importance that Ashford places on firm-specific factors comes from dynamic economics. Klein considers that the ability of firms to deal with uncertainty through successful innovation is 'determined by internal characteristics' (Klein, 1977, p. 140). However, he conceives these characteristics as operating at the level of *individuals* and their interactions in problem solving. Risk-taking and openness are a function of the diversity and attitudes of the people within the firm. 'The scarce resource necessary for the industry to conserve its ability to engage in unpredictable behaviour is people with a high degree of openness' (Klein, 1977, p. 148), with risk-taking being a function of both biology and the stimulus of competition.

Innovation Process in Dynamic Economics

PEOPLE ⇒ INNOVATION BY FIRMS

Innovation Process in Evolutionary Economics

PEOPLE ⇒ ORGANISATIONAL PROCESSES OF KNOWLEDGE CREATION & LEARNING ⇒ INNOVATION BY FIRMS

Figure 1: Comparison of Innovation Process

Klein's theory does recognise internal organisation, but only to the extent that it constrains or enables people's interactions. The ability of an organisation (or nation) to compete is determined by the character of its people, but there is no attention paid to how the organisation can maintain its character over time or how this can be the basis for sustained competitive advantage. The theory does not have the firm-level factors that are the key features of evolutionary theory: 'firms as organisations that know how to do things' (Winter, 1988, p. 175); context-dependent, tacit knowledge; the influence of path-dependency; experiential learning; unique, inimitable organisational capabilities.

Ashford and Heaton appear to recognise the theory's limitations in operationalising firm-specific factors, while still subscribing to the importance placed by Klein on this aspect. 'Klein's work is most useful in going beyond the confines of the firm-level or industry-level innovation process, and it provides a framework for considering the external stimuli which drive the innovation process' (1983, p. 115).

Ashford and Heaton establish the importance of 'the differences in innovative capabilities' in determining the regulation-innovation relationship. Their work is based on Klein's *Dynamic Economics*, which argues for the role of internal firm characteristics as a determinant of innovation but without putting forward a model of how this relationship can be operationalised, and tested empirically. Part of the reason for this failure is that Klein sees these characteristics as being determined by people. He points towards models of biology and organisational psychology as being appropriate. The theory may be incomplete because of its exploratory nature. *Dynamic Economics* may have been intended more as the frontrunner of a new research programme than a fully developed framework, something supported by Klein's later description of it as 'economic poetry' (quoted in Rostow, 1981, p. 613).

Klein's ideas were not adopted and developed by others, but dynamic economics does however have a connection with the development of evolutionary economics (Nelson 1981, Tushman and Nelson, 1990). Nelson and Winter hold that 'our formal theoretical view is consonant, we believe, with the writings on technical change of...scholars of contemporary industrial technical change and of public policy issues like...[among others] Klein' (1982, p. 40). The two theories share an understanding of dynamic efficiency and a focus on understanding innovation as a basis for understanding economic growth.

There is also a connection between Porter's research and evolutionary economics, albeit a more tenuous one.[41] Porter's debate with neoclassical economics has parallels with the debate between neoclassical and evolutionary economists about the analysis of economic growth and technical change. Furthermore Porter's own conception of the firm and adherence to Schumpeterian competition are entirely consonant with the evolutionary theory of the firm:

[41] This connection has recently been made by other economists (Jaffe et al., 2000).

> The world does not fit the Panglossian belief that firms always make optimal choices. This will only hold true in a static optimisation framework where information is perfect and profitable opportunities for innovation have already been discovered, so that profit-seeking firms need only choose their approach. Of course, this does not describe reality (Porter and van der Linde, 1995b, p. 99).

As outlined above this is the basis for Porter's critique of the neoclassical environmental economics approach. It is also the fundamental point of difference between evolutionary and neoclassical economists. Porterian firms cannot pursue profit-maximising behaviour; they face problems of information, control and organisational inertia. The nature of dynamic competition means that they face problems with the rapidity of change in technical knowledge and in the opportunities open to them; firms are learning institutions in an environment that is characterised by both high uncertainty and the need to innovate in order to compete. 'Companies operate in the real world of dynamic competition, not in the static world of much economic theory. They are constantly finding innovative solutions to pressures of all sorts - from competitors, customers, and regulators' (Porter and van der Linde ,1995a, p.120).

However this conception of the firm is not extended to a developed theory of the firm. Porter explicitly assigns primacy to determinants external to the firm; 'the environment[42] is as or more important to innovation than what goes on inside' (Porter, 1990, p. 791, n. 33). This means that when Porter and van der Linde advance the view that the relationship between physical and economic waste means that compliance with environmental regulation is particularly likely to lead to profitable technical change by firms, they do not possess a framework of firm behaviour within which to explore these relationships.[43] A similar limitation is encountered by Ashford and Heaton (1983), using Klein's dynamic economics. They establish the importance of

[42] Environment is used here not in the sense of the natural environment, but in the more general sense of the institutional environment faced by the firm.
[43] Porter may have recognised this limitation himself. The preface to the second edition of *The Competitive Advantage of Nations* outlines six different areas in which he intends to extend this research, but does not refer to any plans for future research on the impact of environmental regulation is not included (Porter, 1998). He also appears to have accepted Schmalansee's argument that spurring organisational attention on innovation in this area 'may not optimize other variables that contribute to competitveness within the corporate setting' (esty and Porter, 1998, p. 35).

internal firm characteristics, such as differences in innovative capabilities, in determining the regulation-innovation relationship, but again lack a developed theory of the firm which would support detailed investigation of the role of firm-specific factors.

Conclusion

Neoclassical environmental economists reject the possibility that regulation can generate a 'win-win' solution, achieving both environmental protection and economic gains. I have shown that neoclassical environmental economics is not adequate to analyse this question because of its static conception of the firm. Mainstream theory generally assumes that regulation is a constraint on firms' behaviour and the firm's decision to innovate is assumed to be made by applying profit-maximising criteria to a perfectly known set of innovations. Because of these assumptions there has been no systematic consideration of technical change in empirical investigations of the regulation-competitiveness relationship. Using the neoclassical model of a profit-maximising firm with perfect information, neoclassical environmental economists argue that profit-maximising cleaner technology will be adopted by profit-maximising firms without requiring a regulatory stimulus and that regulation can only act as a constraint on firms.

I concur with Porter and van der Linde's rejection of the neoclassical environmental economics position that there is no analytical value in understanding the internal process of regulatory adjustment. However their theory is incomplete in so far as it does not explore the internal firm mechanisms that would achieve this innovation. Crucially they are unable to explain their own assertion that 'environmental regulation does not lead inevitably to innovation and competitiveness or to higher productivity for all companies' (Porter and van der Linde, 1995a, p. 134).

Like Porter, evolutionary economists contend that neoclassical theory is fundamentally unable to analyse economic change. Similarly, both contend that neoclassical theory is hampered by the very foundations on which its assumptions are based, and which deny the main features of change. Evolutionary economics explicitly recognises that processes of economic change and technical innovation are characterised not by perfect information and instant adjustment but by searching, by trial and error, by learning over time and by elements of chance. However Porter explicitly assigns primacy to determinants external to the firm and so does not possess a framework of firm behaviour within which to explore these relationships. Without explicitly acknowledging the evolutionary economics theory of the firm, Porter and van der Linde's conception of firm behaviour has many resonances with this approach. This suggests that evolutionary economics offers a way to explore industry response to environmental change that answers Jaffe et al.'s call for research that considers plant level effects and innovation triggers and yet goes beyond assembling case evidence to provide rigorous and theoretically sound analysis.

Any attempt to understand and analyse the potential for environmental regulation to promote both environmental protection and enhanced productivity requires an understanding of internal firm behaviour. The failure of both neoclassical environmental economics and Porter's theory to provide convincing analysis is rooted in their failure to look inside the black box. The evolutionary theory of the firm, with its emphasis on organisational capabilities as the driver of technical change in firms, provides a framework for the development of a coherent model of the relationship between environmental regulation and firm technical change. The next chapter will discuss the evolutionary theory of the firm in detail and establish why an analysis of the role of organisational capabilities provides the best way to explore the impact of regulation on technical change within firms.

5: Evolutionary Economic Theory

Introduction

The central aim of the thesis is to analyse the potential for environmental regulation to induce technical change in favour of cleaner technology in firms. It has been established that neoclassical theory is precluded from supporting a useful analysis of this question by virtue of its assumptions. As discussed in previous chapters, neoclassical theory has assumed away the need to research regulations that do not use market-based instruments. Furthermore, the theory is limited in its ability to analyse technical change. These limitations have been challenged by the work of Porter and Ashford. They have shown that relaxing the assumptions of rational optimisation and perfect information allows the potential for regulation to stimulate economically beneficial technical change within firms. But these theories have been unable to go beyond developing critiques of the orthodoxy and raising interesting questions. As discussed in the previous chapter I ascribe this to the lack of a framework of firm behaviour within which to explore these relationships. In common with the neoclassical environmental economics, the failure of Porter and Ashford to provide convincing analysis is rooted in their failure to look inside the black box.

Evolutionary economists contend that neoclassical theory is fundamentally unable to analyse economic change. This is a serious charge as it is primarily in situations of change that economic theory is looked to for prediction and explanation; as Hayek said 'economic problems arise always and only in consequence of economic change' (1945). Neoclassical theory is hampered by the very foundations on which its assumptions are based, and which deny the main features of change. Foss (1994) argues that 'the ultimate differentia that separate evolutionary economics from mainstream economics are ontological in nature, in the sense that evolutionary economics takes seriously the idea that economic agents live in an economic universe that is fundamentally open-ended in its possibilities, whereas neoclassical economics does not' (1994, pp. 22). The open economic universe is 'an economic setting in which novelties may emerge' (ibid., pp. 23) and includes not only actual events and empirical observations but the 'generative mechanisms underlying the flux of observable events' (ibid., pp. 23). The closed universe is isolated from other systems and is without potential for endogenous change. As discussed in previous chapters the neoclassical framework has been criticised for 'the poverty of its theoretical assumptions' (Hodgson, 1988, pp. xvii). These assumptions are of given, atomistic individuals, the absence of chronic information problems and the restriction of focus to conditions of (near) equilibrium (Hodgson, 1994). Neoclassical theory requires such closure in order to permit study of the 'constant conjunction of events' or economic regularities and development of deterministic outcomes.

Evolutionary economics is the analysis of the dynamics of economic change. Its primary focus is economic growth, technical change as the main driver of growth, and the behaviour of firms as the institutions that are responsible for translating technical change into economic growth (Nelson and Winter, 1982). Evolutionary economics explicitly recognises that processes of economic change and technical innovation are characterised not by perfect information and instant adjustment but by searching, by trial and error, by learning over time and by elements of chance leading to differential rates of innovation between firms. Firms profit from innovations during adjustment but neoclassical theory does not consider the relations between firms except after all adjustments have been made, in equilibrium. Evolutionary economics has developed as one alternative to the dominant orthodoxy of neoclassical static analysis. It is a holistic approach, looking at the complex feedback mechanisms and dynamic relationships that mean 'most economic systems...derive meaning only in the context of the whole system' (Gowdy, 1985, pp. 319). In this chapter I will present an outline of the development of evolutionary economic theory, with particular focus on the development of a theory of heterogeneous firm differences, driven by unique organisational capabilities, rooted in learning and experience.

Evolutionary Biology and Economics

Evolutionary economics has been developed by applying concepts of evolutionary biology[44] to economic processes (Hodgson, 1993). The idea that biology might provide useful ways of looking at economic issues has a long history. Economists such as Hayek, Walras, Marshall and Veblen have all considered the significance of biological concepts, though without any formal development of an evolutionary economic model. In 1950 Armen Alchian revived this debate with his seminal paper 'Uncertainty, Evolution and Economic Theory'. In it he sketches out the beginnings of an evolutionary way of looking at economic processes. He considers the effects of removing one of the central assumptions of neoclassical theory, that of perfect information and foresight. Introducing bounded rationality, that is, economic agents with imperfect information and imperfect information processing abilities, means conceding that firms are unable to profit maximise. It means that firms respond differently to environmental stimulus and so predictions cannot be made about individual firm behaviour, only about aggregate effects.

His aim in developing this model is twofold. Firstly, he believes that the neoclassical model could and should be made more realistic: 'simplifications are necessary but continued attempts should be made to introduce more realistic assumptions into a workable model with an increase in generality and detail' (Alchian, 1950, n6, p. 213). Secondly, he wants to show that, despite abandoning the unrealistic assumptions of perfect information, foresight and profit-maximising behaviour, 'the analytical concepts associated with such behaviour are retained because they are not dependent upon such motivation or foresight' (ibid., p. 211). Removing perfect information and certainty means that agents cannot know the outcomes of their actions, instead they can only know the probability distribution of outcomes associated with each potential action. Alchian defines uncertainty as 'the phenomenon that produces over-lapping distributions of potential outcomes' (ibid., p. 213, n5), with the result that profit-maximising behaviour is confounded since there can be no rational criteria (beyond

[44] An alternative use of biology in economics is the work of Becker (1976) in developing rational choice theory. Becker views economic principles as having relevance for biology, believing that the two disciplines have 'common root problems which are solvable with similar or identical concepts and toolkit theories' (Hodgson, 1993, pp. 29). It is not evolutionary in approach, but an extension of neoclassical analysis to biology.

preferences) for establishing a maximising distribution. In place of profit maximising as the key motivation Alchian sees the economic system as 'an adoptive mechanism which chooses among exploratory actions generated by the adaptive pursuits of "success" or "profits"' (ibid., p. 211). Explanation is no longer grounded in the decisions of individual economic agents but instead in the 'interrelationships of the environment and the prevailing types of economic behaviour which appear through a process of natural selection' (ibid., p. 213). Competition acts as a selection mechanism, selecting ex post on the basis of realised profits - 'this is the criterion by which the economy selects survivors: those who realise positive profits are the survivors; those who suffer losses disappear' (ibid., p. 213). If the environment remains stable for long enough the successful type of firm will become dominant as other types fail and exit the industry. The dominance of the successful firms will be reinforced by firms acting to achieve survival. The characteristics of successful firms will spread, either by conscious imitation or as a result of trial and error searches. Alchian presents this as the economic analogue of evolutionary biology's theory of natural selection - 'the economic counterparts of genetic heredity, mutations, and natural selection are imitation, innovation, and positive profits' (ibid., p. 220).

In order to show that survival does not depend on any purposive behaviour or motivation by firms but may be achieved simply by environmental adoption, that is that 'success is based on results, not motivation' (ibid., p. 213), Alchian first presents the extreme case of selection on random behaviour, before going on to include adaptive behaviour. All that is required is variety in the set of firms and, without any purposeful behaviour on their part, those firms that meet the selection criteria operating in the environment will succeed and persist. 'As in a race the award goes to the relatively fastest, even if all competitors loaf. Even in a world of stupid men there would still be profits' (ibid., p. 213). Alchian wants to show that even purposeless, random behaviour can still be the basis of a coherent theory capable of prediction and explanation. This model still has a place for the economist: 'with a knowledge of the economy's realised requisites for survival and by a comparison of all conditions, he can state what types of firms or behaviour relative to other possible types will be more viable' (ibid., p. 217). Alchian then introduces his complete model, where random variation and purposive adaptation both have a role in determining firm success or failure. Adaptation is by either imitation of success or by trial and error innovation. Codified imitation can be seen in business conventions such as price leadership, costing rules of thumb, accounting codes and advertising policy, which are all based on 'observed success'. Innovation by trial and error is also important, motivated by 'the hope of great success as well as by the desire to avoid impending failure' (ibid., p. 219). Imitation and innovation serve to reinforce the process of natural selection by diffusing the characteristics of dominant firms through the population.

Alchian's paper has provoked strong views, both within the evolutionary economics school and from other economists. Penrose (1952) and Rosenberg (1992) have both questioned the appropriateness of evolutionary biology as an analogy of economic systems. Penrose's criticism of the use of biological analogies in economics is that they 'lead in most cases to a serious neglect of important aspects of the problem that do not fit the particular type of reasoning employed' (Penrose, 1952, p. 804). She considers that the question of the effects of uncertainty is very interesting but that in using an evolutionary analogy Alchian has overlooked the importance of firm motivation and behaviour. Alchian discusses the failings of neoclassical equilibrium theory in dealing with change without being able to present any explicit theory of growth himself. The 'serious neglect' or weakness of his models lies in the lack of a developed epistemology. This means his analogues of hereditary and mutation, namely imitation and innovation, are only vaguely specified, making it difficult for him to explain competition and firm creation. Alchian's assertion that imitation, innovation and economic natural selection will lead to a predominance of successful firms is belied by empirical work (including Rumelt, 1991) that has shown the persistence of inter-firm differences in performance, differences that are sustained even in cases where the organisational requirements criteria for high performance are widely known (Henderson and Cockburn, 1994a).

Penrose considers Alchian's use of biological analogies to be 'ill-founded' (Penrose, 1952, p. 808), as he does not develop an adequate correspondent for genetic heredity. 'Clearly the one thing a firm does not have in common with biological organisms is a genetic constitution, and yet this is the one factor that determines the lifecycle of biological organisms' (ibid., p. 808). Nelson and Winter (1982) actually drew on Penrose's later work (Penrose, 1959) to overcome this problem of a genetic analogue. They used her concepts of organisational capabilities and the nature of organisational learning to develop the concept of organisational routines as durable units of inheritance. (As an aside, Penrose later indicated that she was less opposed to the use of biological metaphors (Hodgson, 1996, n3, p. 17) and identified herself as an evolutionary economist.)

Rosenberg considers the use of biological analogy as part of a wider inquiry into the aims and methods of economics from a philosophy of science viewpoint (Rosenberg, 1992). He believes that any development in economic theory must meet the requirement that 'any scientific discipline should be expected to show a long term pattern of improvement in the proportion of correct predictions and their precision' (Rosenberg 1992, p. 18). Rosenberg holds that economists appeal to biological concepts to cover up the flaws of methodological individualism: 'the analogy to evolutionary biology is a particular favourite among economists who decline to take seriously the actions of individual agents as an explanatory subject of economics' (Rosenberg, 1992, p. 177). He argues that Darwin's theory of natural selection is limited to generic predictions and hence so is its economic analogy. The limitation comes from the fact that any predictions a theory makes requires application of the theory to a set of initial conditions. In the case of evolutionary theory it is difficult to generate predictions because of the problems in adequately specifying the initial conditions and the element of random variation means any predictions can only be generic and not specific. He criticises this predictive weakness in Alchian's evolutionary theory. 'The only way we can use evolutionary theory to predict the direction of adaptation is by being able to identify the relevant environment that remains constant enough to force adaptational change in proportions of firms'

(Rosenberg, 1992, p. 192). He holds that if the environmental conditions were known, something he considers unlikely, evolutionary theory would be redundant as neoclassical theory could then be used to determine the optimal adaptation.

Contemporary evolutionary economists also disagree about the significance of Alchian's paper. Nelson and Winter hail Alchian as a 'direct intellectual antecedent' (Nelson and Winter, 1982, p. 41), particularly for his focus on 'the importance of examining the role of uncertainty from the *ex post* viewpoint' (Nelson and Winter, 1982, p. 42). An important foundation to their own work on developing an evolutionary theory was work Winter (1964) had done on formally modelling Alchian's theory. They accept that Alchian's work is still located within the neoclassical tradition - they believe that his weakness is in not taking the model to its logical conclusions and rejecting the neoclassical approach. Metcalfe (1989) also sees Alchian's work as important but flawed. His major contribution is to begin an exploration of 'the economic significance of diversity of behaviour' (Metcalfe, 1989, p. 59) but he fails to explain in detail the processes by which this differential behaviour would affect the aggregate pattern of an industry, and he misses an opportunity to extend beyond static analysis to a consideration of the impact of diversity in the behaviour of the surviving firms and the effects on growth.

At around the same time as Alchian's paper appeared Milton Friedman published his famous defence of neoclassical economics, *Essays in Positive Economics* (1953). Friedman uses a simplistic idea of natural selection to suggest that the competitive process is a form of natural selection, and that therefore those firms that have survived must have behaved 'as if' they were profit maximising, an argument that 'sought in competitive selection an alternative route to the conclusions that would follow from optimisation by itself, and thereby to reinforce those conclusions' (Matthews, 1984, p. 95). Friedman uses evolutionary biology as a buttress for the profit-maximising hypothesis whereas Alchian's aim was to use it to develop an alternative. Some evolutionary theorists, such as Hodgson (1993), have dismissed Alchian as an apologist for neoclassical theory. But Alchian himself appears to have anticipated Friedman's argument and opposes it: 'The economist may be pushing his luck too far in arguing that actions in response to changes in the environment and changes in satisfaction with the existing state of affairs will converge as a result of adaptation or adoption toward the optimum action that should have been selected, if foresight had been perfect' (Alchian, 1950, p. 220).

Hodgson sees close parallels between biological evolutionary theory and economics but he is dismissive of those who apply the analogy without any real understanding, where 'the conclusions of that natural science are presumed rather than closely examined' (Hodgson, 1993, p. 197). While Rosenberg believes evolutionary economics represents an easy option for economists who do not want to work on the shortcomings of neoclassical methodological individualism, Hodgson believes that the evolutionary approach offers fruitful new ways of looking at economic processes but is one that must be handled with care and intellectual rigour:

> But biology is not a panacea. The primary reason for turning in its direction is the recognition that economies are made up of living human beings, and are part of ecosystems containing other forms of life. The aim is to bring life back into economics, not to worship another science (Hodgson, 1993, p. 24).

In particular Hodgson looks at modern developments in evolutionary biology that have rejected the idea that natural selection is an optimising agent. 'The adaptationist fallacy is the assumption that all adaptations are necessarily functional and (near) optimal'. This belief is know as Panglossianism, after a character in Voltaire's Candide who believed that nature makes optimal selections and that everything natural is the best it could be. It is the charge of Panglossianism that Hodgson brings against Friedman and Alchian, for inferring that competition and evolution bring efficiency. His argument is that much intellectual creativity stems from the 'creative juxtaposition of two different frames of reference' (Hodgson, 1993, p. 24). While Hodgson holds that there are further advances to be made by continuing to explore parallels between economics and biology, Witt (1992a, 1992b) takes a very different view. He recognises the role evolutionary biology played as a 'creative spark' but has a broader definition of evolutionary economics that includes, but does not require, the use of the biological metaphor.

> It is by no means evident, however, why information generated and processed by human intelligence within the framework of human culture should be subject to similar, or even the same, regularities as those observed for genetic information ... Unlike the latter, new cultural information is searched for and created deliberately in response to problems perceived or imagined by the human mind (Witt, 1992a, p. 7).

He places more importance on the treatment of novelty and innovation: 'for a proper notion of socio-economic evolution, an appreciation of the crucial role of novelty, its emergence, and its dissemination, is indispensable' (Witt, 1992a, p. 3). He echoes Penrose's concerns about both the misapplication and inappropriateness of such analogies and, like her, considers that the study of humans is quite different from the study of animals, and needs to take into account the importance of human will and man's ability to alter his environment. 'Firms are institutions created by men to serve the purposes of men' (Penrose, 1952, p. 809).

The Theory of the Firm in Evolutionary Economics

At the forefront of the new wave of economists who started developing evolutionary models in the 1980s were Richard Nelson and Sidney Winter. Their book, *An Evolutionary Theory of Economic Change* (1982), has been hugely influential and has been credited with the revival of evolutionary economic discourse. Their approach was to develop, and run as computer simulations, formal mathematical models that encompass the complexities and interrelationships involved in firm growth and behaviour. In developing their theory they were, as has been discussed above, influenced by Alchian and Penrose. Another important influence was Schumpeter's work on innovative competition. Their work has encouraged many other economists working in formal modelling, appreciative theorising and empirical research. The nature of competition, the role of organisational capabilities and the growth of firms form the common threads running through all evolutionary economic analysis.

Using the metaphor of biology requires economic analogues for the three essential components of any evolutionary process. Variation provides the population with a range of characteristics. These differences mean that members of the population differ in their ability to succeed in a given environment, that is, variation gives the environment something to select on. Inheritance is the mechanism by which individual characteristics, generated by variation, can be passed on and so persist in the population, allowing time for evolutionary patterns to emerge. Selection, or survival of the fittest, operates by selecting for certain characteristics from the variety of characteristics in a population, based on fitness for purpose.

> Our firms are modelled as simply having, at any given time, certain capabilities and decision rules. Over time these capabilities and rules are modified as a result of both deliberate problem-solving efforts and random events. And over time, the economic analogue of natural selection operates as the market determines which firms are profitable and which are unprofitable, and tends to winnow out the latter (Nelson and Winter, 1982, p. 4).

The basis for firm behaviour and firm differences is Nelson and Winter's concept of a routine, defined as 'all regular and predictable behaviour patterns' (ibid., p. 14). Routines cover activities 'that range from well-specified technical routines for producing things, through procedures for hiring and firing, ordering new inventory, or stepping up production of items in high demand, to policies regarding investment, research and development (R&D), or advertising, and business strategies about product diversification and overseas investment' (ibid., p. 14). Routines define what the firm can do, they are akin to the skills of the firm and they form the building blocks of the firm's organisational capabilities (which define what the firm has the potential to do).

> In our evolutionary theory, these routines play the role that genes play in biological evolutionary theory. They are a persistent feature of the organism and determine its possible behaviour (though *actual* behaviour is determined also by the environment); they are heritable in the sense that tomorrow's organisms generated from today's (for example, by building a new plant) have many of the same characteristics, and they are selectable in the sense that organisms with certain routines may do better than others, and, if so, their relative importance in the population

(industry) is augmented over time (Nelson and Winter, 1982, p. 14, emphasis in original).

Variation, or firm differences, stem from two sources: the effects of random events ('the timely appearance of variation under the stimulus of adversity' (ibid., p. 11)) and routines for deliberate learning.[45] Nelson and Winter define an activity of 'search': 'routine-guided, routine changing processes' (ibid., p. 18) which are themselves routines that 'operate to modify over time various aspects of [firms'] operating characteristics' (ibid., p. 17). 'Our concept of search obviously is the counterpart of that of mutation in biological evolutionary theory' (Nelson and Winter, 1982, p. 18). Following Penrose's conception of the learning firm this search process is shaped by the firm's heterogeneous bundle of resources and so will have a unique outcome. 'Search and learning lead to what ex post may be considered differential 'fitness'' (Dosi and Nelson, 1994, p. 160).

Inheritance of characteristics is ensured by the durability of routines. Nelson and Winter develop their concept of 'organisational genetics' (ibid., p. 9) as 'the processes by which traits of organisations, including those traits underlying the ability to produce output and make profits, are transmitted through time' (ibid., p. 9). Routines are the genes of the firm. They are 'regular and predictable behavioural patterns of firms', consisting of behaviour that has been practised and routinised. Nelson and Winter consider them to be a form of 'organisational memory': remembering-by-doing (ibid., p. 99). It is this memory function that is a source of continuity in the firm and means that routines are the unit of inheritance, analogous to genes.

Selection, or survival of the fittest, operates by selecting for certain characteristics from the variety of characteristics in a population, based on fitness for purpose. The struggle for survival is characterised as Schumpeterian competition, driven by innovation and the firm's objective of profit-seeking (not profit-maximising).

[45] In Darwinian natural selection the only source of variation is random genetic mutation. Nelson and Winter acknowledge that they are using Lamarck's theory of purposeful adaptation, in which successful adaptations learnt by organisms can be passed on to later generations.

Selection is by the competitive environment and evolution (or patterns of change) in institutions, organisational structure, and industry structure is determined by the fitness of the organisation for its environment. While the selection process selects *for* fit routines it will usually select *on* the organisations in which the routines reside: this means that although it is the routine that is the source of fitness, it is the whole firm that prospers or fails.

Schumpeter stresses the importance of innovation and technical advance as an economic driver, albeit without explicit consideration of industrial organisation or structure. The Schumpeterian view holds innovation, not as an optimal selection from a known choice set, but as a gamble made by organisations that hold different views about innovations and their potential for success. Winners and losers are only determined ex post by competition. Neoclassical theory, in contrast, treats technical innovation as an exogenous disturbance, temporarily moving the economy away from equilibrium, which is then restored by a process of adjustment. Schumpeterian competition is characterised by revolutions of technical advance, what he terms 'creative destruction',[46] in that the innovation wipes out the preceding technology; 'competition which commands a decisive cost or quality advantage and which strikes not at the margins of the profits and the outputs of the existing firms but at their foundations and their very lives' (Schumpeter, 1943, p. 84). These periods of creative destruction are then followed by periods of adaptive innovation during which the new technology is developed and diffused. The two phases, of technical revolution and adaptation, together form a long wave.

Nelson and Winter (1982) use elements of Schumpeterian competition, such as the emphasis on invention and innovation, but have chosen to overlook the absence of any treatment of natural selection. Although Schumpeter believes that 'the essential point to grasp is that in dealing with capitalism we are dealing with an evolutionary process' (Schumpeter, 1943, p. 82), he defines evolution in the broad sense of

[46] Hodgson (1993) has rejected Schumpeter as an evolutionary thinker on the grounds that Schumpeter's concept of creative destruction was not as a continuing dynamic process but as punctuations of a Walrasian static equilibrium.

'change' or 'economic development' (Schumpeter, 1954, p. 964).[47] He sees innovation as the driver of economic evolution: 'the fundamental impulse that sets and keeps the capitalist engine in motion comes from the new consumers and goods, the new methods of production or transportation, the new form of industrial organisation that capitalist enterprise creates' (Schumpeter, 1943, p. 82). In Nelson and Winter's model innovation is carried out by search processes, higher-level routines for exploration that guide the firms' evolution and are the sources of firm differences.

In summary, the firm in Nelson and Winter's theory is one whose possible behaviour is determined by its set of routines. This view identifies 'the routinisation of activity as the "locus" of operational knowledge in an organisation' (ibid., p. 104). Routines function as durable storage for non-codified knowledge, allowing for the preservation of knowledge as well as its effective use. Differences in routines, reflecting different experiences, result in differences in the behaviour of firms. The competitive environment acts *ex post* as a selection mechanism. Where differences in behaviour are responsible for competitive advantage they lead to differential rates of growth and survival.

Penrose and Organisational Capabilities

Evolutionary economic theory takes the firm as its unit of analysis, with the proposition that organisational capabilities are central to an understanding of firms and industries. The concept of organisational capabilities[48] was established by Edith Penrose (1959) in her influential work *The Theory of the Growth of Firms* and has provided inspiration not only in evolutionary economics but also in strategic management and the development of the competence-based view of the firm. Penrose sees each firm as being a unique bundle of heterogeneous, organisational capabilities; these capabilities are derived from resources, both physical and human. The firm

[47] Schumpeter explicitly rejected the analogy with biological evolution (1954, p. 789). Despite this, Nelson and Winter 'believe that he would have accepted our evolutionary models as an appropriate vehicle for the explication of his ideas' (1982, p. 39).

[48] Penrose did not use the term 'organisational capabilities', but her concept of 'productive services' is generally taken to be the original use of the organisational capabilities concept. The term 'organisational capabilities' is first used in Richardson (1972) (Best and Garnsey, 1999).

acquires resources but makes use of the *services* of those resources - this distinction is important because one resource may provide many different services, depending on the circumstances of its use, and the knowledge of the firm using it. As the firm's circumstances change, most importantly through experience and growth of knowledge, the possibility arises that it will develop new services from existing resources. Organisational capabilities are the basis of firm uniqueness. Nelson (1991) considers that it is organisational differences, especially in the ability to generate and gain from innovation, that are the sources of durable, not easily imitable, differences between firms. These differences between firms form the basis of competition and differential advantage.

In the Penrosian model of growth the crucial capability is managerial capability, which has an entrepreneurial element that drives growth and an administrative element that ensures the implementation and integration of growth plans. Managerial capability also determines the value of the firm's resources. The value of any resource is specific to the organisational capability bundle that it is part of; this means that, unlike in the neoclassical model, the value of a service does not necessarily equal its market price, nor can it be equalised across firms. Management's valuation is shaped by their learning experiences of past growth. Their perception of risk and of future productive opportunities is shaped by past experience. These combine to form the 'image' that management has of the firm's opportunities for and limits to potential, future growth. Growth is planned, within the limits of the existing resource base to absorb new activity. Growth plans are implemented and ultimately the new activity becomes integrated ("routinised" in Nelson and Winter's (1982) terms). This experience of growth further develops organisational capabilities; existing managerial capability learns from the experience of growing and new resources (physical, labour or managerial) are acquired to carry out the new activity. As long as managerial capability continues to develop the firm can continue to grow, as the 'new' managerial capability will have increased ability to plan and absorb growth, increased ability to extract services from resources and a different perception of risk and productive opportunity. This is very different from neoclassical economics which sees the productive opportunities as being made up of unlimited technical information and capability and limited, fixed resources determined by the price system. In Penrose's model the only role the price system has to play is to provide *ex post* confirmation or rejection of the firm's choices.

The firm is a learning firm, where the value of organisational capabilities is not static but is affected by the dynamic processes of firm learning and growth. Managerial resources benefit from learning: development comes from experience, from new challenges provided by growth, from teamwork within the firm and from new skills. The enhanced productivity of the management resource is then employed to enhance the use of other resources. Penrose's view of the firm as a 'repository of knowledge' (Nelson and Winter, 1982) does not concur with the orthodox neoclassical view of knowledge, something that she was well aware of: 'economists have of course, always recognised the dominant role that increasing knowledge plays in economic processes but have, for the most part, found the whole subject too slippery to handle' (Penrose, 1959, p. 77).

Penrose's conception of knowledge has a lot in common with work done by Polanyi (1966) on *tacit knowledge*. Tacit knowledge is that part of a person's skill that is not easily communicated, that cannot be codified or written down. Tacit knowledge can be hard to observe, to the point that even the people who possess it may not be aware of the fact. It is often context-dependent, such as knowledge developed through problem-solving in a specific organisational context. This means that although knowledge may reside in people it can only be articulated within the organisation - this is how Winter can say that 'firms are organisations that know how to do things' (Winter, 1988, p.175). Tacit knowledge is hard to replicate or imitate. If it can be transferred at all it is only through teaching by example, and then this is only the case with knowledge which is observable. This is what makes an organisational capability into a source of sustainable competitive advantage. The cumulative nature of much knowledge, built up by experience and time is both a source of firm uniqueness and a barrier to imitation. It can also act as a constraint on the firm, as path-dependency can become sub-optimal lock-in.

The Penrosian model of the firm is fundamentally concerned with the dynamic nature of the relationships between organisational capabilities, their development through learning, the environment the firm faces and its potential growth opportunities that is at the heart of the evolutionary theory of the firm. Growth of the firm means new experiences: this experience develops the productive capacity of the firm and shapes it unique strengths. Thus organisational capabilities and growth opportunities coevolve.

Development of the Capabilities Concept

Nelson and Winter brought the importance of Penrose's work to the attention of a new generation of academics. Ironically Penrose's work has received closer reading and fuller development through these later writers than through Nelson and Winter's own work. Nelson and Winter (1982) have a chapter entitled *Organisational Capabilities and Routines*, but nowhere in the text do they define organisational capabilities, nor does it have an entry in the index. The emphasis is on organisational routines as the embodiment of capabilities, and not on organisational capabilities themselves. Nelson (1994) has reconsidered the formal model of Nelson and Winter and now believes that it would benefit from greater emphasis on firm-specific, dynamic capabilities. But the theory of organisational capabilities has received close attention, in economics and even more so in the field of strategic management, which has been more open to the heterodox nature of the arguments of both Penrose and Nelson and Winter than mainstream economics (Hodgson, 1996).

The current close relationship between evolutionary economics and strategic management theory is the result of a convergence of two distinct, intellectual trajectories. In strategic management the competence-based view is a development of a field of study that began 20 years ago with the search for sources of competitive advantage. Competitive advantage was ascribed originally to superior, product market position, then to the possession of superior resources and finally to the dynamic position of superior, organisational capabilities (Collis, 1994). Foss (1996b) makes the distinction that strategic management is usefully informed by, but not synonymous with evolutionary theory. The competence perspective within strategic management focuses on understanding sustainable competitive advantage. For long run competitive advantage to be sustainable it must be based on something rare, unique and inimitable, otherwise the advantage would be eroded by diffusion. Organisational capabilities, as firm-specific products of tacit knowledge and path-dependent experience, were identified by theorists as being unique and inimitable making them likely sources of durable differences between firms and therefore sources of rents (Dosi, Nelson and Winter, 2000). Evolutionary economics has broader goals of understanding technological change, population dynamics and the ontogenetic evolution of firms (Foss, 1996b). The capability concept provides evolutionary economics with the basis for heterogeneous differences between firms, upon which the market selection process can work to produce systemic consequences over time (Dosi, Nelson and Winter, 2000).

Hodgson (1996) has traced the development of the competence-based view within economics. He sees the intellectual antecedents as Smith (learning-by-doing, enhanced by division of labour, leading to dynamic growth process), Knight (the firm as a response to the problems of uncertainty which require exercise of tacit knowledge and judgement about future actions) and Penrose. Hodgson distinguishes evolutionary economics as a subset of the competence-based theories, with the use of biological metaphor as the defining criterion. This is not the view of many current researchers in this field (Henderson, 1994, Teece and Pisano, 1994, Foss, 1993, Nooteboom, 1992, Witt, 1992b) who identify themselves as evolutionary economists but do not make explicit use of biological metaphor. Indeed Winter (1988) himself has written about evolutionary economics without recourse to biological concepts, suggesting that while evolutionary biology may have provided the creative spark necessary for the development of an evolutionary economic paradigm, it is not an essential requirement.

Other modern writers have extended Penrose's work to encompass a learning firm where learning is not restricted to managerial capabilities but where planning and doing are fully integrated. Best (1990) sees the development of extensive inter-firm co-operation, the impetus for which are the gains from increased learning. Lazonick (1992) has considered the importance of organisational capabilities, and the move from managerial capabilities to collective capabilities. He defines organisational capabilities as 'the power of planned and coordinated specialised divisions of labour to achieve organisational goals' (Lazonick, 1992, Ch. 9). The importance of organisational capabilities as a source of competitive advantage increases with the complexity of technology; in industries with high fixed costs of technology this becomes crucial. Chandler (1977) sees the purpose of growth as being 'to permit the continuing use of existing resources as well as to develop new ones'.

Some writers have attempted to build a hybrid framework, synthesising evolutionary economics and Williamson's transaction cost economics. In transaction cost economics the form of governance structure is determined by the optimal configuration of production, transaction and organisation costs. Nooteboom (1992) adds to this the element of dynamic efficiency, 'capabilities to exploit transaction relations for innovation' (Nooteboom, 1992, p. 281). Nooteboom's theory is built on an explicit and rich conception of knowledge and learning. Innovation is driven by learning. Changes in knowledge imply a change in the organisational cognitive model and hence changes in the perceptions of the firm's opportunities (Penrose's 'image'). Learning is hampered by the need to process and interpret large quantities of data, the ability to 'ignore' or screen out irrelevant data being as useful as the recognition of what is valuable. This process is assisted by the development of cognitive categories of thought. However, as this process becomes more efficient and tacit so the ability to be flexible and open to novelty is reduced; the process may 'harden' to the point of becoming 'an epistemological obstacle' (ibid., p. 289), screening out information necessary for innovation. The efficiency of learning can be improved, and some of the difficulties of tacit and path-dependent knowledge overcome, by developing a partnership with another organisation. There is a trade-off to be negotiated in any such arrangement as too dissimilar a partner will involve high transaction costs of building and maintaining a relationship, while promoting dynamic efficiency and innovation requires exposure to a partner with a sufficiently different cognitive framework. The optimal governance structure is chosen not solely 'to satisfy present demands, but to create a potentiality for the satisfaction of future demands' (ibid., p. 296).

Langlois and Robertson (1995) have developed a theory of 'dynamic transaction costs' that places primary importance on the role of capabilities in determining growth. They see the competitive advantage of a firm deriving from its 'intrinsic core', defined as 'idiosyncratically synergistic, inimitable and noncontestable' (Langlois and Robertson, 1995, p. 7). This intrinsic core is underpinned by knowledge, including tacit knowledge developed by people learning to work together in 'institutionally specific ways' (ibid., p. 13); it only faces possible erosion if competitors happen to acquire the same knowledge. Langlois and Robertson see the maintenance and development of capabilities as being vital to the long run success of the firms; dynamic transaction costs are the 'costs of not having the capabilities you need, when you need them', they arise in situations of unpredictable change and when there are problems with appropriability of innovations.

Langlois and Robertson have a Penrosian conception of growth, driven by surplus resources into areas that, while not necessarily related to existing end products, have a synergy with existing capabilities. The boundaries of the firm, and the locus of new activity, are decided by the strength of the firm's capabilities relative to the market's capabilities, that is, the cost of making rather than buying capabilities. The local and path-dependent nature of firm learning means that firms can better exploit their 'intrinsic core' capability by linking up with other firms to gain access to the complementary 'ancillary capabilities'. The nature of this relationship will be determined with respect to static and dynamic efficiency considerations; the firm will manage the change internally if the costs of using the market are too high, either the traditional information-type transaction costs of asset-specificity and opportunism or the dynamic costs, 'costs of persuading, negotiating and coordinating with, and teaching others' (Langlois, 1992, p. 99). The two limit cases are: (1) in the case of autonomous innovation, that is change affecting just one part of the production chain, and when markets offer a high level of capability relative to the firm, horizontal or vertical specialisation will be the preferred governance structure; (2) in the case of systemic innovation, affecting more than one part of the production chain, and when the market does not possess the capabilities to handle the innovation as a decentralised network, a vertically integrated firm will be the preferred governance structure.

Teece et al. (1994) have used the nature of organisational learning and the development of competencies to look at corporate coherence, that is, why, empirically, corporations have diversified into *related* activity. Organisation learning has a cumulative and collective character, and it is dependent on 'employment in particular organisational settings' (ibid., p. 15). This means that 'opportunities for successful new developments will be 'close-in' to previous activities' (bid, p. 17). Prahalad and Hamel (1990) are strategic management theorists who have done important work on this kind of growth. They identify 'core competencies', crucial to the growth and survival of firms. They believe that a successful company builds a portfolio of core competencies that give it a strong basis for developing successful businesses. Rapid technical change may erode the profitability of an end product but core competencies are more enduring and more difficult to imitate. Prahalad and Hamel stress the nature of path-dependency: a missed opportunity to acquire a core competency may mean catching up in the future will cost much more. Successful firms identify and internalise strategically significant competencies, recognising the importance of building knowledge, even when in the short run this entails losses.

Definitions of Organisational Capability

The literature has struggled to develop a definition of organisational capability or an explicit delineation of the relationships between competence, capability and routine. 'The term "capability" floats in the literature like an iceberg in a foggy Arctic sea, one iceberg among many, not easily recognisable or different from several nearby' (Dosi et al., 2000, p. 3).

The tacit and embedded nature of capabilities makes direct observation difficult, and means that they are most usefully defined in relation to the *outcomes* or *performance* that they enable (Dosi et al., 2000). 'Capabilities are the least definable kinds of productive resources. They are in large measure a by-product of past activities but what matters at any point in time is the range of future activities which they make possible' (Loasby, 1998, p. 144). 'Competences/capabilities are capacities for structuring and orienting clusters of resources – and especially their services – for productive purposes…' (Christensen 1996, p. 114). Capabilities can be 'characterised as the capacity to generate action' (Cohen at al, 1996, p. 683). 'Competences/capabilities which are ways of getting things done which cannot be accomplished merely by using the price system to coordinate activity' (Teece et al., 1997, p. 517).

Possession of a capability is indicated by achievement of an outcome with *competency*. 'A typically idiosyncratic knowledge capital that allows its holder to perform activities – in particular to solve problems – in certain ways, and typically to do this more efficiently than others' (Foss, 1996a, p. 1). Loasby describes this as 'the structured combination of skills which underlies effective performance' (1999, p. 50).[49]

At the core of the organisational capability concept is its basis in *knowledge*; capabilities are 'a particular kind of knowledge' (Loasby, 1998, p. 140) and the firm

[49] Although effective (rather than efficient) performance is usually determined by the test of the external environment; 'what level of performance is "good enough" at any time depends on those … who make the judgement … The effectiveness of any capability, even in a familiar situation, is never definitively established' (Loasby, 1999, p. 60)

is a repository of knowledge (Nelson and Winter, 1982). Kogut and Zander warn though that not all organisational knowledge can be considered to be capability.

> In fact the knowledge of the firm, as opposed to learning, is relatively observable: operating rules, manufacturing technologies, and customer data banks are tangible representations of this knowledge. But the danger of this simple characterisation is that everything that describes a firm becomes an aspect of its knowledge. While this is definitionally true, the theoretical challenge is to understand the knowledge base of the firm as leading to a set of capabilities that enhance the chances for growth and survival (Kogut and Zander, 1992, p. 384).

There is little guidance from the literature on when knowledge and routinised behaviour can be considered a capability, and when it cannot. In another paper, Zander and Kogut argue that the 'capabilities of the firm consist of the cumulative experience in understanding a class of knowledge and activities' (1995, p. 77, emphasis added). It is a level of understanding that allows the knowledge to be applied to *problem-solving*: 'an idiosyncratic problem-solving knowledge capital (Foss, 1996a, p. 8), 'problem-solving skills' (Coriat and Dosi, 1998, p.111). This suggests that understanding can be used as a characteristic that distinguishes the knowledge underpinning a capability from other organisational knowledge.

Capability is generally considered to represent a *cluster* of components: 'a hierarchy of practised organisational routines which define lower order organisational skills and how these are coordinated and higher order decision procedures for choosing what is to be done at lower levels' (Chandler, 1992b, p. 85). 'When firm-specific assets are assembled in integrated clusters spanning individuals and groups so that they enable distinctive activities to be performed, these activities constitute organisational routines and processes' (Teece et al., 1997, p. 516).

Some writers subdivide capabilities. Dosi and Teece (1993) suggest that competency can be divided into organisational (covering production methods, make or buy choices and organisational structures to enable efficient performance) and technical (product development and efficient operation). Christensen identifies technical capability, being 'specialised capacities in which the technical dimension is dominating, while the managerial element is narrow in scope' (1996, p. 115), providing the firm with a technology base and 'favourable options for technology-related diversification in the long-term' (ibid., p. 125). Christensen's definition emphasises that the differences are not discrete but a question of degree, echoing Nelson and Winter's caveat that '...skills, organisation, and "technology" are intimately intertwined in a functioning routine, and it is difficult to say exactly where one aspect ends and another begins' (1982, p.104).

More recently the literature has begun to emphasise that not all capabilities have the same potential for achieving change. Christensen defines capability as a 'lower-order functional or inter-functional technical capacity to mobilise resources for productive activities,' distinguishing this from competence, which is the 'higher-order managerial capacity of the firm or corporate management to mobilise, harmonise and develop resources and capabilities to create value and competitive advantage' (1996, p. 115). Teece et al. develop a concept of higher-order capabilities. 'We define dynamic capabilities as the firm's ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments. Dynamic capabilities thus reflect an organisation's ability to achieve new and innovative forms of competitive advantage given path dependencies and market positions' (Teece et al., 1997, p. 516).

The development of concepts such as dynamic capabilities may be seen as a response to criticism that the automaticity implied in Nelson and Winter's concept of routines means that the evolutionary economics theory of the firm is as deterministic as the neoclassical theory of the firm (O'Sullivan, 2000).[50] In their original work Nelson and Winter neglect organisational capabilities and focus on organisational routines. Fransman (1994) suggests that they focus on the 'simple and stylised' concept of routines to facilitate their purpose of modelling the relationship between technical change and economic growth but that the deterministic implications of routine are not

[50] Other writers have made similar arguments about the limits of models that rely on path-dependence but do not give a role to agent reflexivity and strategic action. These include Sabel (1996) and Tracey et al. (2002).

present in the discursive (or 'appreciative theorising', to use Nelson and Winter's own term) sections of the book.

> In some of our models, the higher-order decision rules of policies with which we endow our firms may metaphorically be interpreted as their strategies. In these models firms have different strategies, and a central analytical concern is the viability of profitability of firms with different strategies. And although in the models described in this book we do not permit our firms to change their strategies, such changes are quite admissible within the logic of our theory (Nelson and Winter, 1982, p. 37).

It is clear that within evolutionary economics the development of the firm is seen as being strongly path-dependent. Teece et al. (1994) argue that the future direction of the firm is partly a question of the technical opportunities open to the firm. These may be the result of internal innovation, or they may be developed externally to the firm through developments in basic science or by other firms. In either case however, the exploitation of these opportunities by the firm relies crucially on its 'knowledge base and organisational context' (Teece et al., 1994. p. 16), that is, on the firm's capabilities. The technical opportunities that the firm is best able to explore will lie thus 'close-in' to existing technologies used by the firm (Teece and Pisano, 1994, p. 546). This is reinforced by the fact that 'in addition, a firm's past experience conditions the alternatives management is able to perceive' (Teece et al., 1997, p. 524), a point made originally by Penrose (1959) who argues that the learning from past growth acts to shape the 'image' held by manager of future potential growth. This means that firms in the same industry may be making decisions about future activity on the basis of (a) different costs for pursuing the same technical opportunities and (b) a different set of perceived technical opportunities (Teece and Pisano, 1994).

> It is quite inappropriate to conceive of firm behaviour in terms of deliberate choice from a broad menu of alternatives that some external observer considers to be "available" opportunities for the organisation. The menu is not broad, but narrow and idiosyncratic; it is built into the firm's routines, and most of the "choosing" is also accomplished automatically by those routines (Nelson and Winter, 1982, p. 134).

However, that is not to say that evolutionary economics does not allow for deliberate, reflexive or strategic behaviour by firms.

> Undoubtedly, there is a great deal of business behaviour that is not, within the ordinary meaning of the term, "routine." Equally clearly, much of the business decision making that is of the highest importance, both from the point of view of the individual firm and from that of society, is nonroutine. High-level business executives do not, in the modern world, spend humdrum days at the office applying the same solutions to the same problems that they were dealing with five years before. We do not intend to imply any denial of these propositions in building our theory of business behaviour on the notion of routine (Nelson and Winter, 1982, p.15).

Zollo and Winter (2001) have carried out an exploration of the nature and source of dynamic capabilities, which is 'a significant clarification of the structure of the phenomena' (ibid., p. 37). They distinguish dynamic capabilities, which they define as 'systematic change efforts' (ibid., p. 8), from organisational routines which are 'geared towards the operational functioning of the firm' (ibid., p. 4) and are the outcome of 'incremental improvements...accomplished through the tacit accumulation of experience and sporadic acts of creativity' (ibid., p. 8). They consider that dynamic capabilities derive from learning mechanisms that 'go beyond semi-automatic stimulus-response processes and tacit accumulation of experience' (ibid., p. 10). Dynamic capabilities include an element of experiential learning, but are also the outcomes of more deliberative cognitive processes aimed at developing explicit knowledge: 'dynamic capabilities emerge from the co-evolution of tacit experience accumulation processes with explicit knowledge articulation and codification activities' (ibid., p. 19). These processes of 'collective learning' (ibid., p. 10) 'achieve an improved level of understanding of the causal mechanisms intervening between the actions required to execute a certain task and the performance outcomes produced' (ibid., p. 10). This type of learning can result 'in adaptive adjustments to the existing sets of routines or in enhanced recognition of the need for more fundamental change' (ibid., p. 11). Zollo and Winter's developed conception of dynamic capabilities captures the strategic actions of deliberate reflection on firm learning and capability.

Identifying organisational capabilities requires being able to identify absence of capabilities. The theoretical literature makes it clear that, because of their tacit and cumulative component, capabilities cannot be acquired by firms and that therefore absence of capabilities is not something that can be easily remedied. 'Organisations are poor at improvising coordinated responses to novel situations; an individual lacking skills appropriate to the situation may respond awkwardly, but an organisation lacking appropriate routines may not respond at all' (Nelson and Winter, 1982, p. 125).

> If current knowledge is inadequate, it may well be that a firm does not know what changes are required in the existing principles and structure of relationships. Even if identified they may not be feasible, because the relational structures in the organisation would be disturbed (Kogut and Zander, 1992, p. 392).

Much of the organisational capabilities research is related to strategic management concerns about sources of competitive advantage. This has left a gap in the literature concerning the implications of the absence of capability. Research focussing on a particular capability underpinning competitiveness can assume that alternative sources of competitive advantage are open to firms that do not possess the capability in question. Henderson and Cockburn (1994b) looked at capabilities for R&D in the pharmaceutical industry, but assume that firms that do not possess the capability to support a competitive advantage in R&D could otherwise have competitive advantages based on marketing or clinical trial management.

The literature is also unclear about at what level of aggregation capability should be considered to reside. Illustrative examples are often given of low level routines, such as a routine for faxing a press release to the media (Cohen et al., 1996). In practice capabilities are analysed at high levels of aggregation, such as quality, miniaturisation (Teece et al., 1997), R&D (Henderson and Cockburn, 1994a), process development (Pisano, 1994) and corporate acquisitions (Zollo and Singh, 1999). A workshop held on research issues in this area failed to agree on the 'grain-size' or boundaries of routines (and by extension capabilities) (Cohen et al., 1996). Dosi et al. conclude that a capability is a 'fairly large-scale unit of analysis' (2000, p. 3), without giving direction as to how this level might be established.

The definition of capability in theory remains imprecise. Considerable debate still remains about the level of automaticity within routines; the balance of relationships between routines and capabilities; the relationships between technical and organisational capability; and between static and dynamic capability (Cohen et al., 1996). This imprecision extends to identifying capabilities in applied work: 'the capabilities of an individual or a firm can rarely be precisely defined' (Loasby, 1999, p. 59). The 'failure' to develop a standard taxonomy of organisational patterns may be purposeful: Winter has proposed 'that achieving maximum tightness in key definitions may sometimes inhibit progress' (Cohen et al., 1996, p. 684). From the literature it has been possible to reach an approximation of the characteristics of an organisational capability in order to operationalise the theory in the applied part of the thesis.

Theoretical Framework of the Thesis

Dosi, Nelson and Winter propose that dynamic capabilities are defined at broad level (e.g. capability to develop manufacturing processes, capability to design drugs etc) but are 'consisting of a collection of more narrowly defined competences, closely overlapping with effective routines, brought together through mechanisms and organisational structures that influence how they work as a whole' (2000, p. 127). To use a biological analogy, the cheetah possesses a (high-level) capability for being a meat-eater and its survival is secured by the proficiency with which it can hunt. This capability is made up of a cluster of different components: the right type of claws and teeth; leg form and muscles for pursuit at high-speed; a gut that will digest meat; the brain processes to be a hunter; the social organisation to support predation. A cheetah's meat-eating capability is rooted in genes that allow for a number of integrated and clustered behaviours, including resources, learning, problem-solving and organisation.

Using evolutionary economics to analyse the potential for environmental regulation to induce technical change in firms requires developing measures for organisational capabilities. The knowledge that the firm needs to respond to the new regulatory environment resides in the organisational capabilities of the firm, defined by Teece et al. as 'a measure of the firm's ability to solve both technical and organisational problems' (1994, p. 18). The organisational capabilities therefore define what the firm is potentially able to do in response to the new regulatory demands. Organisational capabilities 'constitute the experience base of the firm' (Christensen, 1996, p. 113). This suggests that the ability of a firm to respond to a changed regulatory environment will be a function of the existing set of capabilities within that firm.

Taking Robertson's definition of how organisational capabilities develop - 'through working together people learn to behave in institutionally specific ways that are efficient but cannot be easily, cheaply or quickly taught to others' (Robertson, 1996, p. 81) - we can see the two influences identified by Nelson and Winter (1982). Firstly, the firm initiates the deliberate processes of 'search', that is, directed learning and development of new patterns of behaviour in order to meet strategic requirements. Secondly, the impact of random, unanticipated events will result in learning, new experience and therefore development of the organisational capabilities; Nelson and Winter refer to this as 'the timely appearance of variation under the stimulus of adversity' (1982, p. 11). The external regulatory environment has the ability to stimulate both of these types of influence and hence affect the development of a firm's organisation capabilities. Firms may identify a strategic need to develop environmental management capability. Response to unanticipated environmental demands could also lead to the development within firms of experience and capability in environmental management.

Many writers have made the distinction between static (Teece et al., 1994) or lower-order (Christensen, 1996) capability, representing the practice and replication of well understood, routinised managerial or technical skills and the dynamic or higher-order capability required for learning, innovation and strategic development. Static capabilities are the 'technical capacity to mobilise resources' (Christensen, 1996, p. 115), and relate to specialised and narrow skills. In the context of this study I identify static capabilities for environmental management. Firstly, static technical capabilities, in terms of technical skills and resources, will determine the firm's effectiveness in the implementation of environmental technologies. Secondly, static managerial capabilities will determine effectiveness in administration and coordination of environmental management systems. Dynamic organisational capabilities are the capabilities involved in recognising and responding to the need to develop new capabilities. They are the capabilities that determine the rate and direction of learning, and the firm's strategic development.

> The term 'dynamic' refers to the capacity to renew competences so as to achieve congruence with the changing business environment... The term 'capabilities' emphasises the key role of strategic management in appropriately adapting, integrating, and reconfiguring internal and external organisational skills, resources, and functional competences to match the requirements of a changing environment (Teece et al., 1997, p.515).

Organisational capabilities are by definition, as the embodiment of tacit and context-dependent knowledge, difficult to observe and therefore measure. Capabilities are expressed through routines (Nelson and Winter, 1982) defined as 'the way things are done in the firm... or patterns of current practice and learning' (Teece et al., 1997, p. 518). 'It is the routines themselves and the ability of the management to call upon the organisation to perform them that represents an organisation's essential capability' (Teece et al., 1994, p. 15). This research uses the presence of observable static and dynamic organisational routines for environmental technology, management and strategic development to infer the presence of capabilities.

From the literature, capabilities are 'in large measure a by-product of past activities but what matters at any point in time is the range of future activities which they make possible' (Loasby, 1998, p. 144). We would expect that when changes in the external environment call for a change in technology, such as a change in the emphasis of environmental legislation, firms may find it difficult to respond if they do not possess the requisite capabilities. 'Firms are heterogeneous with respect to their resources/capabilities endowments. Further, resource endowments are 'sticky': at least in the short run, firms are to some degree stuck with what they have and may have to live with what they lack' (Teece et al., 1997, p.514). Capabilities are largely the result of cumulative and experiential learning, which limits a firm's ability to respond by developing their own capabilities internally; capabilities have a large tacit component, which makes it difficult for a firm to imitate another firm's success. 'Organisations are poor at improvising coordinated responses to novel situations; an individual lacking skills appropriate to the situation may respond awkwardly, but an organisation lacking appropriate routines may not respond at all' (Nelson and Winter, 1982, p. 125).

In the evolutionary theory of the firm organisational capabilities and growth opportunities coevolve. The firm is a 'knowledge creating entity' (Foss, 1996b, p. 191). Experience develops the productive capacity of the firm and shapes its unique strengths. In turn, the nature of existing capabilities will influence the perception of and capacity for future growth. Organisational capabilities are the basis for persistent firm heterogeneity. Where they underpin fitness with the firm's environment the result is differential rates of growth and survival. 'Firms are seen essentially as repositories of competence' and it is the 'firm's ability to accumulate, protect and deploy competences' (Foss, 1996a, p. 1) that determines long run success.

Applications of Organisational Capability Theory

Empirical work, using evolutionary theory and focusing specifically on capabilities has proved fruitful in identifying the evolution of firms' capabilities and their relevance to firm performance and industry competition.

One strand of research uses organisational capabilities to explain broad scale shifts in national industrial development. Chandler, an economic historian, has used the concept of organisational capabilities to explain origins of the modern corporation and the rise of mass production in the US during the 19th century (1992b). He places stress on the early-mover advantages of learning and the 'knowledge-acquiring processes of growth' (Chandler, 1992b, p. 84) and considers organisational capabilities an important barrier to entry. Chandler agrees with Penrose on the prime importance of managerial services; he holds that while physical capabilities determine the *potential* economies of scale and scope that can be exploited, it is the management capability that is crucial in determining the *actual* extent of the economies reaped. Similarly, Fransman (1995) and Fujimoto (1998) have used organisational capabilities to look at industrial development in Japan. Fransman explains the evolution of the computer and communications industry in terms of competence development. Fujimoto identifies the processes of capability building that underpinned the introduction of world class manufacturing techniques. In these broad analyses of economic history organisational capabilities are not measured precisely. Through a process of retrodiction, the presence of organisational capabilities presence is inferred from looking at historical patterns of success and failure, developing plausible theories to explain the observed outcomes.

Much of the organisational capability research is focussed at industry level, and is broadly aimed at developing explanations of observed, firm-specific and persistent differences in firm performance within given sectors. Henderson and Cockburn (1994b) look at the hypothesis that 'idiosyncratic firm capabilities both shape diversification and drive the performance of diversified firms' (ibid., p. 63). This was inspired partly by previous quantitative work (Henderson and Cockburn, 1994a) which finds that variance in research productivity could be explained by 'firm fixed effects' and that although differences in research portfolios have a significant effect on research productivity these differences are 'both large and persistent'. In the 1994b paper they look to explain heterogeneous firm competencies. They look for relationships between firms' research productivity and evidence of (a) component competence, locally embedded knowledge and skills and (b) architectural competence, the ability to use component competencies and to develop new architectural and component competencies as required. They measure component competence as firm specific expertise in particular scientific disciplines and disease areas. Architectural competence is measured as the ability to coordinate and foster information flows, both within the organisation across project boundaries and from outside the firm. The results support competencies as a source of resource productivity. The results are explored further in case study research (Henderson, 1994) that focuses on the contingent factors affecting the evolution of competence and drawing out the difficulties that firms face in acquiring new capabilities. Acha and von Tunzelmann develop qualitative indicators of capability, having 'concluded that measuring technological strength through traditional innovation metrics was unhelpful and misleading' (2001, p. 10). They capture elements of the firm's 'technology frame' (similar to the Penrosian concept of 'image') through qualitative assessment of (i) attitude to future development (pursuing either a growth or efficiency strategy); (ii) importance given to role of technology (presence or absence of explicit representation in communications and at board level); (iii) strategic use of technology (exploited for only profit potential or used to enhance reputation and therefore future position).

Another strand of research aims to unpack organisational capabilities and organisational learning processes. Absorptive learning capacity is a firm's ability to assimilate and exploit existing information (Cohen and Levinthal, 1990). Knudsen et al. (2001) develop indicators of absorptive capacity based on the preconditions for successful access by firms of existing knowledge: openness to collaboration, the base of knowledge within the firm and the type of knowledge being accessed. Using survey data they are able to show a positive relationship between possession of these indicators and the incidence of successful innovation projects. Flaherty (2000) looks at the different stages of knowledge and the associated processes of organisational learning. She identifies the 'need for managers to bound the ways in which individuals exercise initiative in accumulating process knowledge' (ibid., p. 100). Moving from simple learning, such as problem measurement and control, to learning embodied in a capability, such that root causes are eliminated and the knowledge can be leveraged into other areas, benefits the firm, but requires costly and uncertain investment of effort, and may be potentially disruptive to production. Pisano (1994) looks at the creation of new organisational capabilities for process development. He compares process development projects in mature chemical pharmaceutical companies with the newer biotechnology companies. The more mature industries are able to use their long experience to replicate plant conditions in the laboratory and move to full-scale production with the minimum of disruption. The biotechnology companions, facing a less certain environment, maximise the efficiency of their process development by using on the job development. Pisano establishes two different learning processes underpinning capability development: learning-by-doing (tacit accumulation of experience) and learning-before-doing (deliberative knowledge articulation and codification).

Conclusion

While the literature surveyed in this chapter covers the extensive theoretical development that has advanced the work of Nelson and Winter, it reveals some of the substantial questions that remain. The concept of capability is still loosely defined. The theory is only slowly approaching 'a parsimonious vocabulary' (Zollo and Winter, 2001, p. 38) and clear delineation of the relationships between routines, technical, managerial and dynamic capabilities. The theory suggests that knowledge is stored in routinised behaviour, but absence of capability, and the failure of routinised knowledge to become capability has not been explored. The origins of dynamic capabilities are similarly neglected. Questions about the balance between the tacit and inimitable elements of capability and the role of intentionality require further exploration. Undoubtedly some of these questions remain open because of the paucity of empirical work (Foss, 1996b; Cohen et al., 1996; Zollo and Winter, 2001). This is compounded by the finding of Becker (2001) that there is very little integration of empirical findings back into the theoretical debates, notwithstanding that many of the questions raised above are not amenable to being answered by theory alone. The intention is that the research presented in this thesis will contribute to advancing knowledge in these areas.

6: Researching Organisational Capabilities

Introduction: The role of organisational capabilities

Measuring capability is an attempt to measure complex, embedded, tacit and context-dependent patterns of knowledge and practice. Capabilities may not be directly observable, and may not even be understood or articulated by the capability holders. Measuring capability requires in-depth data on internal firm behaviour. In this research I have used secondary data made available as part of the IPC regulations. These data have allowed me to develop measures that capture (i) indicators of historical capability prior to licensing; (ii) patterns of technical activity within the firm with respect to environmental technology; and (iii) the development and operation of routines for management of environmental activity. In addition, I have collected qualitative primary data through case study research that has allowed me to explore the more subtle, contingent issues around capability development and deployment. The research will attempt to capture the different elements of capabilities for responding to environmental regulations. These are suggested by both the theoretical literature on organisational capabilities and the literature on corporate environmental management.

Research Questions

The purpose of this research is to examine the impact on firms of the introduction of environmental regulation aimed at promoting the adoption of cleaner technology and improved environmental management.

The essence of the evolutionary theory of the firm is that the firm is a repository of knowledge, that this knowledge resides in the organisational capabilities of the firm and that these organisational capabilities then determine the firm's performance. The theory suggests that not all firms will be able to respond to the new regulation as the regulators intend. Firms will be differentially successful in the take-up of cleaner technology solutions. They will also differ in the extent to which they have successfully introduced the managerial changes required by the regulators. The theory has identified dynamic organisational capabilities as being a key factor in managing change. These capabilities are defined in chapter five as firm-specific, non-tradable assets, and firms will differ with respect to the possession of routines and capabilities for environmental problem-solving and strategic development. It is predicted that firms with these dynamic capabilities will have been more successful in meeting the requirements of the new legislation. Specifically firms with dynamic capability are more likely to have been successful in the development of static managerial capabilities and are more likely to have been successful in the uptake of cleaner technologies.

As well as examining the influence of organisational capabilities on firm performance and success, this research explores the origins and evolution of firm-specific capabilities. The hypothesis that dynamic capabilities are central to a firm's ability to adapt to a changed regulatory environment is further explored by examining in detail the organisational processes for problem solving and strategic development. I look at specific examples of firm experiences in generating and implementing new technologies and management techniques, as well as the use of organisational processes for articulating and codifying new organisational concerns and knowledge into routinised behaviour. The choice of case-study firms allows these questions to be explored in the context of examples of both successful and unsuccessful experiences.

In the evolutionary theory of the firm organisational capabilities are the by-products of past learning and experience. One element of this path-dependent view is Penrose's argument that the influence of past learning and experience on the direction of future performance is embodied in the firm's 'image' or perception of its specific future opportunities and environment. In the case study research attention is paid to the different ways in which firms perceive their environmental management performance. An assessment is made of how influential this perception has been in determining the firm's environmental management strategy in specific decisions. Path-dependency is explored by looking at how the current capabilities set has evolved from past activity and experiences, and how this influence persists, despite capabilities also being affected by more explicit strategic processes.

The introduction of new legislation in Ireland affords a unique opportunity to study the role of organisational capabilities. Organisational capabilities determine the extent of a firm's fitness with the environment it operates in, and as such underpin growth and survival. The test of organisational capabilities provided by the changed regulatory environment is a strong test for the presence or absence of the requisite capabilities. Success in the competitive environment can be achieved through different capability sets; a firm that does not have strong product development capabilities may still have a competitive advantage in marketing. The IPC licence conditions operate as a uniform test that throws the absence of capability into stark relief, as firms do not have the possibility to compensate for lack of capability with an alternative capability set.

Another benefit afforded by studying capabilities in this context is that for this sector, environmental management is not considered to be a source of competitive advantage. These firms are not concerned about protecting their environmental knowledge, as it is not, for the most part, commercially sensitive. In fact, the firms in this sector are very aware that the environmental performance of every firm has the potential to impact all firms in the sector, and see co-operation and sharing of environmental management knowledge as important and beneficial to the sector as a whole. Researching organisational capabilities in a setting where firms are not actively trying to prevent diffusion of knowledge provides a strong test of the firm-specific and inimitable nature of capabilities.

Furthermore, as discussed in chapter five, capability research has traditionally focussed on areas related to competitive advantage. In this research the role of organisational capabilities in determining firm behaviour in non-core areas of activity can be established. A further advantage of this research is that under the regulations, firms are obliged to submit extensive and detailed data on their environmental management and activities, in a uniform format, subject to audit by the regulators. This has allowed for the development of capability indicators that are more detailed than could have been achieved through survey research, across a wider range of firms than could have been achieved by case study research.

In summary, this research will establish the role of organisational capabilities in determining a firm's ability to effect the necessary technical change and to manage the adaptation to a changed external environment.

Measuring Organisational Capabilities

The IPC regulations mark a significant change in terms of the amount and type of environmental information that firms have to provide to the regulators. This increased level of information provision is combined with a philosophy of transparency and openness with respect to public access to information. The information available at the EPA is extensive; it includes the initial IPC licence application (see table 1), monitoring results, reports of audit visits by the Agency, correspondence between the firms and the Agency and the firm's annual environmental reports (AER). These reports are submitted to the EPA with details of all environmental projects being carried out by the firm, with measurable goals, target dates and progress.

The Freedom of Environmental Information Act (1990) establishes a legal right to access environmental information. In addition, as a condition of their IPC licence, firms are obliged to make information available at the site. Almost all documentation held by the EPA relating to firms is available for public consultation; exceptions are only made where the firm has requested confidentiality for reasons of commercial sensitivity. Under the old licensing regime (1970-1992) it was sufficient for firms to provide local authorities monitoring reports of emissions and there were no guaranteed rights of public access.

Activity	Details of products; description of typical manufacturing processes; details of materials used, especially any high toxicity materials.
Environmental Considerations	Overall environmental approach: cleaner technology employed, treatment systems, waste minimisation, raw material substitution projects.
Fugitive Emissions	Details of programme to measure and if necessary reduce emissions from pumps, valves, pipes, vents.
Emissions to Air	Source, volume, character, treatment and discharge of waste streams.
Emissions to Water	Source, volume, character, treatment and discharge of waste streams.
Emissions of Solid Waste	Source, volume, character, treatment and discharge of waste streams.
Programme to meet BATNEEC	Details of in what respect the plant falls short of BATNEEC standards. Plan and timescale for actions to achieve compliance.
Emergency Procedures	Evidence of planning and procedures for accident and major incident situations.
Decommissioning	The procedures that would be followed to secure the safety of the site should the activity cease.
Site Management and Control	Details of reporting structure, responsibilities. Management programme, projects, targets & goals.

Table 1: Information required in IPC licence application

The type of information available has implications for testing the two hypotheses. This information is available for two distinct points: (i) the IPC licence application provides detailed information on the firm's environmental management and environmental technology, at the time of licensing; (ii) the records held by the EPA relating to the operation of the licence provide detailed information on the development of the firm's environmental management and environmental technology. This rich data set allows the development of a set of measures of organisational capabilities that might be expected to have determined the firm's ability to meet the requirements of the new legislation.

Measuring Organisational Capability – Historic Capability Measures

Organisational capabilities evolve over time with the accumulation of learning and experience. The firms in this study have only five years of experience of the new licensing regime, and it is too soon to be able to expect to see any the influence the new regulatory environment may have had on the development of firm capability. It is therefore necessary to test this hypothesis by looking at the possible impact of the previous licensing regime, which was operated from 1970 to 1994, on the development of organisational capabilities. There is however no correspondingly detailed data available on the environmental management of firms *before* the introduction of IPC licensing. Using data made available at the time of licensing on past practice, it is possible to infer limited measures of capability relating to past environmental management. These measures reflect: the stringency with which firms were regulated historically (LOCN); compliance with previous regulations (BATNEEC); historic environmental control (GW); level of environmental knowledge (TIME).

Regulatory Stringency

Prior to the establishment of the EPA firms were regulated by local authorities. It is generally acknowledged that Cork County Council had the most developed competence in legislating pharmaceutical manufacturers[51] and that the legislation was more strictly applied and enforced in Cork than in other local authorities.[52] Irish industrial policy had been to encourage pharmaceutical and chemical companies to locate in the Cork harbour area. Cork County Council was therefore responsible for a relatively large number of firms and this allowed it to build up greater resources and experience in enforcement. The concentration of firms also meant that the environmental performance of these firms became a high-profile issue for local citizens and the focus of NGO pressure. This external scrutiny provided increased impetus for rigorous enforcement by Cork County Council; it provided pressure for

[51] Interview with Ian McLean, Director, IPC Licensing, Environmental Protection Agency, June 1997.
[52] Interview with Matt Moran, Director, Irish Pharmaceutical and Chemical Manufacturers Federation, June 1997.

self-regulation from responsible firms who did not want their reputation compromised by the actions of other firms. The former head of enforcement at Cork County Council, now Director for Licensing at the EPA, attributes it to 'partly public pressure, partly NGO pressure, partly regulatory pressure and partly it was just the peer pressure.'[53] The cohort is not large enough (16 firms) to provide a detailed exploration of the relative stringency of all 9 local authorities with responsibility for these firms. It does however provide evidence of the difference between firms regulated by the local authority recognised as being the most stringent, and having the greatest competence, and responsible for almost half the cohort (7 out of the 16 firms are Cork based) and all the other local authorities (8 local authorities with responsibility for 9 firms).

LOCN: Measured as:

1: firms regulated pre-1994 by stringent Cork County Council;
0: firms regulated pre-1994 by any other local authority.

Regulatory Compliance

BATNEEC (best available techniques not entailing excessive cost) is a framework concept used in setting EU regulatory standards for industry. Regulators define the level of environmental control to be employed by firms based on what is technically achievable. Regulators must take account of two sets of economic criteria: (a) the gains in environmental quality achieved weighed against the costs to industry (cost-benefit analysis) and (b) the affordability of these technologies in the sector (Sorrell, 2001). Emission limit values (ELVs) are set by regulators so as to be achievable with currently available technologies. This is the BATNEEC standard:

> BATNEEC means *"the best available technology not entailing excessive costs"*. The technology in question should be **Best** at preventing pollution and **Available** in the sense that it is procurable by the industry concerned. **Technology** itself is taken as the techniques and the use of techniques, including training and maintenance etc. NEEC addresses the balance between environmental benefits and financial expense (EPA, 1996, p.4, emphasis in original).

[53] Interview with Ian McLean, Director, IPC Licensing, Environmental Protection Agency, June 1997.

The EPA issues a guidance note of appropriate technologies which have been used to set the ELVs. Firms are obliged to meet the ELVs, but are not limited to using the technologies defined in the guidance note:

> The BATNEEC identified in the Guidance Note is used as a basis for setting emission limit values... Technologies identified in the BATNEEC guidelines are considered to be current best practice for the purpose of setting emission limit values. These technologies are representative of a wide range of currently employed technologies appropriate to particular circumstance (EPA, 1996, p. 3).
> However, the guidance issued in this note in respect of the use of any technology, technique, or standard does not preclude the use of any other similar technology, technique, or standard which may achieve the same emission... (EPA, 1996, p.3).

BATNEEC is defined with an emphasis on technologies for pollution prevention over treatment. 'In the identification of BATNEEC, emphasis is placed on pollution prevention techniques, including cleaner production technologies and waste minimisation, rather than end-of-pipe treatment' (EPA, 1996, p. 3). 'BATNEEC will be used to prevent, eliminate or, where that is not practicable, limit, abate, or reduce an emission from an activity...' (EPA, 1996, p. 3). For new facilities the BATNEEC standard is held to be the ELVs set by the guidance note. For existing facilities the requirement to balance environmental benefits and financial expense means that a lower level may be determined to be BATNEEC for that facility. 'The BATNEEC guidelines are not the sole basis on which licences' emission limit values are to be set, since information from other sources will be considered including site-specific environmental and technical data, plant financial data and other relevant information' (EPA, 1996, p.4).

> For existing facilities, additional regard shall be had to:
> - the nature, extent and effect of the emission concerned;
> - the nature and age of the existing facilities connected with the activity and the period during which the facilities are likely to be used or to continue in operation, and
> - the costs which would be incurred in improving or replacing these existing facilities in relation to the economic situation of activities of the class concerned. (EPA, 1996, p. 4)

In issuing the first round of IPC licences the EPA revised and tightened the water emission levels for most firms; these levels had not been revised since the original water pollution licenses were issued in the 1970s. This tightening was signalled well in advance and many firms upgraded their water treatment facilities in the early 1990s. The air emission levels were not tightened; as the legislation was recent, the BATNEEC that had been defined for compliance was still current,. Furthermore firms had either just completed or were still engaged in a programme of investment to ensure air standards compliance. The EPA did however change the BATNEEC guidelines to include pollution prevention technologies, as discussed above. In their application for an IPC licence firms were asked to identify whether or not they were in compliance with the BATNEEC standards, and where necessary to provide details of their plans to upgrade to these standards. The EPA has made explicit its intention that *all* facilities should work towards attaining current BATNEEC, notwithstanding the provision of the legislation that it is mandatory only for new facilities. For firms that had not achieved BATNEEC by the time of their IPC licence application the EPA made compliance a condition of the licence, specifying the pre and post compliance emission levels and the date for achieving full compliance.

BATNEEC: Measured as:

1: firms that had achieved compliance with both air and water BATNEEC standards at the time of applying for an IPC licence.
0: firms that had not achieved compliance with both air and water BATNEEC standards at the time of applying for an IPC licence.

Environmental Control

A measure of past environmental performance is provided by the introduction of a requirement for groundwater testing. As a condition of their IPC licence firms are required to establish ground water monitoring wells on site. In addition to ongoing monitoring, they are required to carry out a once off investigation to determine whether historical groundwater contamination has taken place. An example of a typical groundwater investigation condition is given below:

10.4.7 The licensee shall undertake a comprehensive investigation of the quality of the groundwaters under the site. All sources of

> contamination shall be identified and isolated to prevent further contamination. A proposal for remediation of any contamination which has taken place shall be drawn up. A report shall be submitted to the Agency within 6 months of the date of grant of the licence, and a programme of improvements shall be undertaken within 1 year of the date of grant of this licence (EPA, IPC Licence for SmithKline Beecham, Reg004, 1994).

This type of contamination could be caused by long-term poor environmental management of pipes, bunds, valves etc. leading to uncorrected leakage. It could also be the result of a once-off accidental spillage in an otherwise well run facility. These two possible causes mean that groundwater contamination is a somewhat imperfect indicator, but it still provides a valuable proxy for historical performance. For example, in one plant: 'Environmental considerations played an important role at an early stage in determining site layout and choice of facilities. Such considerations are also reflected in the processes and process systems used on site' (IPC Licence Application, 1994).

> We are here now operating 10 years and we have not had one complaint. That is a little unusual in our business, that's different in truth. And that's the way we started and that's the way we will continue on...Even if you consider the plant that was built back here in 1986, it has been drastically revamped. Standard pipes had been put in, they have all been dug up. Double containment has been put in, we upgraded all the systems.[54]

From the presence of uncontaminated groundwater, it can be inferred that firms possess routines and procedures necessary to ensure good environmental control.

GW: Measured as:
1: firms with uncontaminated groundwater, proved by testing;
0: firms where testing revealed contaminated groundwater.

State of Environmental Knowledge

The EPA's goal in determining the licence conditions for a firm is to minimise the total environmental impact of the firm. This requires significantly more information

[54] Interview with CEO of Pharma A, 1998.

about the operation of the plant, as well as the environmental operations, than firms would have been accustomed to providing under the old licensing system.

> One of the reactions from industry to all of that was 'you are looking for too much information', so we said 'fine, please tell us which bits of this do you think are irrelevant and unnecessary' and industry couldn't tell us. So IPC has to be that, because again you have to go right back into all the raw materials that are being used, indeed not just the raw materials that are being used but all materials that are being used on site. ... So there is a very wide range of chemicals and all of those have to be identified. All the processes have to be identified and where each waste stream arises has to be identified.[55]

Section 85(1)(b) of the Environmental Protection Agency Act (1992) sets down the requirements for the EPA's licensing procedure. Each licence application is assigned to an EPA inspector. The inspector has responsibility for assessing the application and determining the conditions of the licence. The EPA maintains the Integrated Pollution Control Register of Licences; the register records all the formal stages of the licensing process. Under Article 10 the inspector must determine whether the application is complete in providing all the information necessary to determine the licence. If the application is incomplete, under Article 11(2)(b) the inspector is empowered to request that the firm provide the necessary additional information, and may make as many requests as are required. The date of the requests and the date of the firm's compliance with the request are recorded in the Register. Even after the Inspector has declared the licence in compliance with Article 10, under article 17, further requests for necessary information may be made to the firm. Again, the date of the requests and the date of the firm's compliance with the request are recorded in the Register.[56]

This information allows the development of an indicator of the state of a firm's environmental knowledge at the time of the IPC licence application. The indicator is the total number of days that the firm took to respond to an EPA request for further information. This measure comprises two elements. Firstly, it measures the incompleteness of the original application, as reflected in the number of requests for

[55] Interview with Ian McLean, Director, IPC Licensing, Environmental Protection Agency, June 1997.

[56] Other articles cover requests for information on other matters: planning permission (12(3)(b)); environmental impact statement (13(1), 13(2), 14(2)(b)); abandonment of the licence (24(2)); objections and oral hearings ((31,

FIRM	LOCATION	BATNEEC	TIME	GW
Pharma A	CORK	✔	75	[57]
Pharma B	CORK		53	
Pharma C	CORK	✔	40	✔[58]
Pharma D	KERRY		39	✔
Pharma E	DUBLIN		15	✔
Pharma F	CORK	✔	41	✔
Pharma G	TIPPERARY		141	
Pharma H	CORK	✔	48	✔
Pharma I	CORK	✔	35	
Pharma J	CLARE		292	
Pharma K	CORK	✔	7	✔
Pharma L	WICKLOW		53	
Pharma M	SHANNON		57	
Pharma N	DUBLIN		115	
Pharma O	DUBLIN		36	✔
Pharma P	DUBLIN	✔	40	✔

Table 2: Indicators of historic environmental capability

further information and the significance of those requests.[59] Secondly, it provides a measure of the firm's responsiveness in providing the information requested. For example, Pharma D took 39 days to complete its application and the required information related to two points of clarification, covered by three pages of information on details of stack heights and volume of air emissions; in this case Pharma D's comparatively low score of 39 days categorises it as having a good level of environmental knowledge. Pharma N took 115 days to provide documentation to

32; 33, 34, 39(2), 40).

[57] Cara's groundwater testing programme is on-going, and the conclusive report will not be submitted to the EPA until August 2000. However, both the company and the EPA inspector have given a high priority to the testing programme. Given that there is a concern on the part of the EPA, and in the absence of a definite report, I am assuming a result of contamination.

[58] Janssen's testing programme found evidence of groundwater contamination. The testing also determined however, that the contaminated groundwater was migrating onto the site, having been polluted elsewhere. For my purposes therefore, they are not considered to have contaminated groundwater.

[59] Some requests could relate to something as simple as a missing site map. Other requests related to the firm's failure to provide full characterisation of air and water emissions content and volume.

satisfy 18 points of clarification needed to complete its application; with this relatively high score of 115 days the plant is categorised as having poor or weak environmental knowledge.[60]

TIME: Measured as the total number of days taken to satisfy EPA requests for information to complete the IPC licence application.

Conclusion – measures of historic capability

The IPC licensing process can be used as a reassessment of the progress companies had made towards meeting their obligations under prior legislation. Firms that were previously licensed under the varying standards of interpretation and enforcement operating in different local authorities were, in the course of the IPC licensing process, measured against a uniform, national standard. This provides an insight into the impact of differing regulatory standards pursued by local authorities. The requirements of IPC licensing demand a substantial, complex and integrated response by firms covering environmental management, planning, continuous improvement and pollution prevention as well as environmental impact. Compliance with legislation prior to 1992 required a simpler and discrete response that related only to the implementation, operation and monitoring of air and water BATNEEC technology. The measure of BATNEEC compliance allows us to identify, broadly, differences between firms in the level of environmental activity or investment in environmental technology. It does not however tell us about the effectiveness with which the requisite abatement technology is being operated nor does it indicate the development of an organisational capability for problem-solving with respect to managing environmental impact. In this research, measures are developed that infer the presence of capabilities in these areas. Testing for the presence of contaminated groundwater is taken as a proxy for past effective environmental control. The time taken by firms to provide the EPA with full and complete documentation in support of their IPC licence application is taken to be a proxy for the level of the firm's knowledge of its own environmental impacts.

[60] It should be noted that the measure does not discriminate between a firm that took a long time to respond to a simple request and a firm whose application was missing substantial and complex information. However, as both types of delay represent a lack of environmental knowledge, this is not an unreasonable lack of precision.

Measuring Organisational Capability – Capability for IPC Compliance

The EPA has made clear (EPA, 1997) that it expects firms to move away from a focus on end-of-pipe technology. End-of-pipe technology can be defined as 'downstream waste treatment' (Christie, 1995, p.31). The EPA's explicit preference is that emission standards be met through the use of cleaner technology. Cleaner technology has been defined as 'approaches to manufacturing that minimise the generation of harmful waste and maximise the efficiency of energy use and material use' (Christie, 1995, p.31). Firms are expected to demonstrate a commitment to implementing pollution prevention over waste treatment. In addition the regulators require firms to show continuous improvement in environmental performance, and to support this with procedures for environmental planning and management. In evolutionary economics terms, firms are required to have static technical capabilities for cleaner technology adoption and static managerial capabilities for environmental management.

Measure of Technical Capability in Cleaner Technology

Analysis of the firms' IPC licence applications and the annual environmental reports (AERs) submitted between 1995 and 1999 allowed me to compile detailed information on 800 projects carried out in the cohort of 16 firms. The data are a fair representation of firms' environmental activity. Projects were excluded from the analysis where they were subsequently reported as being on-hold or suspended. Similarly, if a project was reported in one year, but no information on either progress or completion was given subsequently, it was excluded. In total 193 projects were excluded from the analysis. The projects are not weighted to take account of project size. In the main large projects are reported as a series of related sub-projects. Furthermore while firms did have projects that comprised significant single investments (between IR£1million and IR£18million), it is not the case that these firms had concentrated their environmental activity in a few large projects, and would have their environmental effort underreported by an unweighted count of projects.[61]

[61] In total, 33 large projects were identified, with between 0-6 large projects per firm. 7 firms had between 3-6 large projects; their average number of projects per firm was slightly larger than that of the group that had

I have categorised these projects in three different respects.

(i) I have categorised projects according to where in the manufacturing process they are located: production; cleaning[62]; utilities; waste treatment and disposal; environmental management.

This is based on Smith and Petela (1992) who have identified a 'structured approach to waste minimisation based on the hierarchy intrinsic to chemical processes' (p. 9.1). This hierarchy identifies the *location* of waste minimisation possibilities, starting at the core of the chemical process, the reactor and works outwards. Waste minimisation at the level of the reaction is the most complicated to effect, but offers the greatest potential for waste minimisation; beyond that there are opportunities in separation and recycling, utilities and finally waste.

(ii) I have categorised projects according to the *techniques* involved, based on the classification developed in INFORM (1992):

Chemical route changes include the substitution of raw materials and significant change to the chemical pathway used to produce the drug, such as the number and type of reactions, separations and isolations. Significant changes of this kind require the approval of national drug regulators (such as the US FDA) for re-registration of the changed chemical route.

Process changes involve minor changes to the chemical process employed, such as improving process efficiencies by making adjustments to the temperature conditions under which reactions take place.

Operations changes improve the operation of a process, but do not involve changes to the process itself, such as operating processes with greater accuracy at critical points.

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between 0-2 large projects per firm.

[62] Cleaning is a significant element of pharmaceutical manufacture. The plants are operating on a batch-manufacturing basis. The changeover from production of one drug to another requires rigorous cleaning of all production equipment using large amounts of solvents, in accordance with the procedures laid down by national drug regulators (such as the US FDA Good Manufacturing Practice).

Equipment changes where the primary change has been the addition or modification of equipment.

(iii) I have categorised projects according to the EPA's (1996) hierarchy of preferred approaches, according to whether the *outcome* was: reduction in waste produced; recycling to avoid waste; or treatment of waste.

Using the classification developed above, I have identified end-of-pipe projects as those that are (i) waste based; (ii) primarily use equipment; and (iii) result in treatment. Cleaner technology is a broader category of project, as it includes all approaches that result in the production of less waste either through source reduction or recycling. These measures capture the extent to which a firm has complied with the EPA's requirement to adopt cleaner technology solutions to environmental control.

WET	The percentage of a firm's total projects (from time of licensing to 2000) that are end-of-pipe technologies.
CT	The percentage of a firm's total projects (from time of licensing to 2000) that are cleaner technologies.

Given the influence of the cumulative and path-dependent nature of organisational learning on a firm's capability to exploit technical opportunities we would expect to see firms developing related projects, that is, a concentration or clustering within firms of projects of a particular type. The detailed analysis of the types of projects undertaken by firms, using the classifications above, shows that in many of the firms we see clusters of related projects, that is, a firm pursuing a number of projects in the same area, using the same techniques. A firm is considered to have a cluster of cleaner technology projects, or specialised technical capabilities when (i) more than 20 percent for a firm's total projects fall within one category and (ii) the percentage of projects in this category is at least double the average percentage for the cohort as a whole. An end-of-pipe cluster is where a third or more of the firm's projects are related to equipment for waste treatment.

STC Scores were assigned to each firm:

2: firms with a cluster of cleaner technology projects;
1: firms without any clustered projects;
0: firms with a cluster of end-of-pipe projects.

As a condition of the IPC licence firms are required to pursue elimination or reduction of List I and II substances. List I and II substances were defined under the Paris Convention[63] as dangerous substances that all countries should strive to eliminate. Pharmaceutical manufacture relies heavily on the use of solvents for isolating active ingredients and cleaning equipment. Many of these solvents are volatile organic compounds (VOCs) which have been shown to have harmful environmental effects and are targeted by the Paris Convention.

> The licensee shall put in place a programme to identify methods by which a reduction in emissions of List II substances, and all priority black list substances, from the activity may be achieved. The licensee shall provide a report to the agency on an annual basis, setting out reductions achieved with regard to the these compounds in the previous year, and also setting out targets for the improvements in the following year (IPC Licence No. 15, condition 2.4).

List I/II Firms were scored on their record of List I/II source reduction.

4: firms that have achieved elimination of a List I/II substance;
3: firms that are attempting elimination;
2: firms that are only pursuing reduction projects;[64]
1: firms that have not undertaken any projects;
0: firms that have stated that they will not consider any projects.

Drug production processes are subject to high inefficiencies; in a process with a number of steps the final weight of active ingredients produced may be in the order of 10% of the inputs. At the point where a licence to market is sought for a new chemical entity (NCE) from the relevant national licensing authority (the most important of which is the US FDA) the chemical route or process by which the NCE is produced is registered and cannot be altered without the risk of significant cost, delay and difficulty. Improving the chemical route by which active ingredients are

[63] An international treaty, signed by the member states of the Council of Europe, under which signatories agreed in principle to the elimination of emissions of toxic and persistent chemicals, especially chlorinated solvents.
[64] These firms have limited their actions to improving the efficiency of solvent use, without being prepared to consider total elimination.

produced is the area with the greatest potential for waste reduction, but also the area in which pharmaceutical plants face the most constraints, regulatory and commercial.

CR percentage of a firm's total projects (from time of licensing to 2000) that are chemical route change projects.

It might be expected that firms with strong process development capabilities would be in a better position to develop both chemical route change in general, as well as projects to reduce use of List I/II substances. The firms were assessed on the strength of their process development capability.

PD Plants were scored as

2 (lead plant,[65] has a pilot plant, and a large number of staff),
1 (firms carrying out some process development work) or
0 (firms that rely on corporate process development functions).

Measure of Environmental Management Capability

The explicit aim of the IPC licensing system is the development in licensed firms of an environmental strategy focused on cleaner technology. 'The main environmental objective of IPC is to prevent or solve pollution problems rather than transferring them from one part of the environment to another' (EPA, 1996a, p. 2). From the EPA's guidance note (1997) it is possible to identify the key elements that the Agency expects to see in an environmental management system. These are: measurable objectives and targets; management procedures and documentation, both of which are expected to produce demonstrable continuous improvement.

> 3.2 Schedule of Objectives and Targets
> 3.2.1 Purpose
> The purpose of this requirement is to ensure that there are clear environmental goals within an organisation as a whole. Goals should be set to achieve a year-on-year improvement but not necessarily in every area of the activity, i.e. they are strategic and not short term.
> Targets should be demanding, in that they should require a special effort to achieve them. There is little point in setting targets at a low level as they provide little motivation or satisfaction upon achievement. In any case low level targets are unlikely to be

[65] Within the corporation, a lead plant is a strategic manufacturing site, used for the launch of new drugs.

> approved by the Agency and may result in licence Inspector establishing targets for the specified project. Objectives and Targets should be quantified where ever this is practical to ensure that real attainment is recorded against the targets.
> The objective is a comprehensive set of targets and objectives, from the boardroom to the shop floor, integrated into the day-to-day business activities of the managers and staff. (EPA, 1997, p. 8)

> The Environmental Management Programme is often described as the *engine* for continuous improvement, but an Environmental Management System, like any vehicle, is of little use with an engine alone. Hence the requirement for the additional elements which in the main are related to the housekeeping function of the EMS e.g. document control, record-keeping, corrective actions etc. (EPA, 1997, p. 7)

Scores were assigned to each firm for its level of organisational capability in both the development of an environmental management system and in the use of measures and targets for continuous improvement, based on progress reports made to the EPA in the AER and audit reports produced by the EPA. In addition, from the literature on organisational capabilities, we would expect that responding to the challenges of the new licensing regime with an effective environmental strategy would require dynamic capability. A measure of routines for information generation, problem identification and solution and strategic development was developed. It corresponds to the search routines defined by Nelson and Winter (1982): routines for the identification and development of new routines. Here I have assessed each firm for evidence of environmental search routines. Table three outlines the criteria used to assign scores to each firm for managerial and dynamic organisational capability. Table four gives the scores and rationale for each firm in the cohort.

Systems

The development of a system of documentation and procedures

4	• Routinised and integrated EMS • EMAS accreditation
3	• EMS established but not fully operational • Adapting existing EMS to IPC requirements
2	• EMS developed after IPC licence granted • On-going work to develop EMS • EMS system but with an abatement focus
1	• Indication of intention to develop EMS • Criticism by EPA of EMS weaknesses
0	• No dedicated environmental manager • No formal EMS

Measures

The development of measurable targets based on systematic data collection

4	• Measures in 5+ areas • Long established or broad coverage • EMS driven by measures
3	• Measures in 4+ areas • Used for targets and actions • Established and integrated into EMS
2	• Measures in 2+ areas • Evidence of use for targets/actions • Intention to integrate into EMS
1	• Measures in only 1or 2 areas
0	• No measures or • Only once-off use of measures

Strategic Development

The development of the systematic pursuit of continuous environmental improvement

4	• Established routines for data collection and problem identification • Established programmes for generating pollution prevention projects • Established use of cross-functional continuous improvement teams
3	• Systematic identification of pollution prevention projects • Recent introduction of continuous improvement teams • Integration of problem-solving capability into EMS
2	• Recent/limited adoption of routinised data collection or problem-solving • Data collection without use in follow-up problem-solving
1	• No systematic pursuit of pollution prevention • Evidence of environmental management problems due to incomplete information
0	• Absence of pollution prevention projects • Explicit abatement only focus • Significant delays in IPC application process due to lack of information

Table 3: Criteria for Scoring Environmental Management Capability

	STRATEGIC DEVELOPMENT	MEASURES	SYSTEMS
Pharma H	Evidence of Strong Routines • 1997 energy: self-audit & reports • 1997 waste management group • corporate procedures on information for waste minimisation and continuous improvement SCORE: 4	Extensive use of measures/targets • Water; gas; electricity use • Hazardous/non-hazardous waste • Recycled/incinerated solvents • Fugitive emissions SCORE: 4	Established/routinised EMS • 1996 EMAS • 1996 corporate SE2000 EMS • EPA set limited audit requirements, on basis of past record/ EMAS SCORE: 4
Pharma C	Evidence of Strong Routines • Cross-functional continuous improvement teams • Extensive use of external help • Pushed/advised HQ R&D for cleaner processes SCORE: 4	Extensive use of Measures/Targets • 1991 Air/water emissions • 1991 Solvent; chlorinated solvent use • 1991 Hazardous/non-hazardous waste SCORE:4	Established/routinised EMS • corporate reporting system • 1997 ISO14001 SCORE: 4
Pharma P	Evidence of Strong Routines • systematic evaluation of environmental impacts as basis for planning environmental mgt actions e.g. profiles of water/ energy/waste use • co-op with corporate HQ and external advice • policy of rotating staff between Env/Manuf investing in Process Development to increase learning and knowledge SCORE:4	Extensive Use of Measures • Air; water; brine; energy use • Chlorinated solvent use • Fugitive emissions • No specific targets set in EMP, but areas of change identified SCORE:4	Established/routinised EMS • 1997 EMAS • 1997 ISO14001 • EPA set limited audit requirements, on basis of past good performance and EMAS SCORE: 4
Pharma I	Evidence of Routines • 1989 Technology Transfer System – liaison with HQ R&D 4 years before new production begins • 1992 Waste minimisation programme with targets • 1997 Waste minimisation x-functional team – water SCORE:3	Use of Measure/Targets • Solvent usage by product stream • Solvent discharge to water • 1998 product yields: progress/targets • Waste reduction; carbon usage SCORE:3	Formal EMS • Environmental corporate checklist • 1994 EU energy audit pilot scheme • residual management plan SCORE:3
Pharma D	Evidence of Strong Routines • extensive use of planning and studies • 1994 consultants developed info and programme of waste reduction for BATNEEC compliance • programme to assess new production • 1995 consultants developed further programme of waste reduction for cost savings SCORE:4	Use of Measure/Targets • Solvent mass balance (1993) • Waste; energy reduction • Extensive VOC emissions reduction SCORE:3	Developing formal EMS • 1994 environmental mgt group • environmental procedures SCORE:2
Pharma K	Evidence of Routines • 1989 cross-functional task force – WWTP • 1992 waste minimisation group for solvent reduction – extensive HQ collaboration/advice • EMP includes HQ and plant level continuous improvement, including teams SCORE:3	Some Use of Measure/Targets • Annual solvent mass balances with reduction targets • 9 projects with reduction targets • planned register of effects/targets SCORE:2	Formal EMS • 1996 3 year plan to pilot EMS to common corporate standard • 1998 ESP corporate environment product introduction process SCORE:3

Table 4: Measures of managerial capability: scores and underlying rationale for each firm

	STRATEGIC DEVELOPMENT	MEASURES	SYSTEMS
Pharma E	Evidence of Developing Routines • 1997 procedure for increased information on packaging waste • O/F/G problems – after equipment solution failed began exploring procedure changes SCORE:2	Use of Measures/Targets • Solvent mass balances/consumption • waste; energy; water reduction • oil; fats; grease emissions • 1995 EPA criticised lack of targets SCORE:3	Little evidence of formal EMS • EH&S review committee • 1996 EPA criticised lack of waste minimisation policy and EMS/ programme SCORE:1
Pharma A	Evidence of Developing Routines • 1993 extended pilot plant to increase waste minimisation • 1995 established database of process knowledge • systematic use of audits (e.g. water; energy) SCORE:2	Extensive Use of Measures/Targets • 1988 water; utilities consumption • 1988 ammonia sulphate; COD • 1988 solvent use SCORE:4	Little evidence of formal EMS • references only to QMS and environmental SOPs • 1997 training in environmental management from IBEC SCORE:1
Pharma M	Evidence of Developing Routines • IPC: took 7 months to provide full information • 1996 3 month study to reduce water use • 1997 using PER information to develop reduction programme • 1998 participated in EPA waste red pilot scheme SCORE:2	Some Use of Measures/Targets • plan to develop/set targets • plan for detailed process mapping • solid; liquid; clean waste emissions • solvent reduction SCORE:2	Developing formal EMS • ISO310 • 1997 developing indicators/targets for environmental management programme SCORE:2
Pharma F	Evidence of Developing Routines • extensive use of studies of receiving environment • 1995 waste minimisation committee • environmental focus groups in each production unit SCORE:2	Limited Use of Measures/Targets • organic solvent reduction • solvent mass balances SCORE:1	Developing formal EMS • environmental quality system – with containment focus • EPA unannounced audit SCORE:2

Table 4: Measures of managerial capability: scores and underlying rationale for each firm

	STRATEGIC DEVELOPMENT	MEASURES	SYSTEMS
Pharma J	NO Evidence of Routines • 1995 unaware of full extent of 1990 air regulations • IPC: took 292 days to provide full Information • Plans for waste reduction and yield improvements but no evidence of achievements SCORE:0	Limited Use of Measures/Targets • Waste reduction/recycling targets SCORE:1	Little evidence of formal EMS • 1998 ISO14001 • 1996 EPA enforced changes to procedures; maintenance; monitoring • 1996 prosecuted by EPA SCORE:1
Pharma L	Limited Evidence of Routines • 1991 waste minimisation committee (4/ p.a.) • 1990 unaware of full extent of air • IPC – could not determine nature of air emissions • PD is strong; tackles environmental problems, but not integrated with EMS or environmental management function • EPA refused permission for abatement solution to WWTP emission problem – mandated waste minimisation solution be developed SCORE:1	Limited Use of Measures/Targets • Liquid ammonia reduction (1991–96) • chlorinated solvent reduction SCORE:1	Developing formal EMS • 1994 pursuing IS310 (national environmental management system standard) • 1997 ISO14001 accreditation SCORE:2
Pharma G	No Evidence of Routines • review of waste streams for optimal abatement • high level of reporting on abatement performance SCORE:0	Limited Use of Measures/Targets • IPC waste minimisation index – calculated as once-off exercise • 1997 solvent recovery measures SCORE:1	Little evidence of formal EMS • 1998 consultants to explore development of formal EMS • EPA unannounced audit SCORE:1
Pharma N	Limited Evidence of Routines • IPC took 115 days to provide full information • 1998 continuous improvement group – yields • waste minimisation committee (4 meetings p.a.) SCORE:1	Very Limited Use of Measure/Targets • water meters installed SCORE:0	Developing formal EMS • 1992 corporate programme with emissions focus • 1998 ISO14001 SCORE:2
Pharma B	No Evidence of Routines • IPC application missing information on technology; products; processes • Waste minimisation role unfilled for 3 years SCORE:0	Limited Use of Measures/Targets • 1992 annual solvent mass balance • 1995 reduction targets set • 1999 energy review put on hold SCORE:1	No evidence of formal EMS • 1999 set goal of developing EMS SCORE:0
Pharma O	No Evidence of Routines • appealed IPC licence because application had underestimated firm's environmental effects SCORE:0	Very Limited Use of Measures/Targets • 1996 energy audit SCORE:0	No evidence of formal EMS • no environmental manager • lack of procedures criticised by EPA SCORE:0

Table 4: Measures of managerial capability: scores and underlying rationale for each firm

Statistical Analysis of Capability Indicators

Analysis of the indicators is performed using nonparametric measures of association and related tests of significance. The choice of non-parametric measures was determined by the nature of the data. The use of nonparametric tests is advisable where the data cannot be assumed to be normally distributed, and also where the sample size is small. More importantly, nonparametric tests can be used where the data can be ranked in an ordinal scale, but where a more exact measure of the differences between ranks, that is, an interval scale, cannot be established (Siegel and Castellan, 1988). These conditions apply to the data used in this study. The sample size, although the entire population, is small, comprising sixteen firms. The population is not normally distributed. The measures discussed above allow for firms to be ranked on various indictors, but most of the measures do not allow for the construction of a more precise interval scale. For any given indicator, one firm can be shown to be better than another, but the strength of the difference, how much better, cannot always be established. The extent of correlation in data based on ranks, can be tested for using either the Spearman rank-order correlation coefficient or the Kendall rank-order correlation coefficient. Both statistics use the same information, and although for a given set of data, the numerical values differ between the two statistics, 'both will lead to rejection of the null hypothesis ... at the same level of significance' (ibid., p. 251).

The data have a high proportion of tied observations; the presence of tied scores requires amendment of the ranks, so that 'each of them is assigned the average of the ranks that would have been assigned had not ties occurred' (ibid., p. 239). It is also necessary to use a correction factor in the computation of the statistic, otherwise the strength of the correlation would be overstated. Standard statistical analysis packages, such as SPSS, do not adjust for the presence of tied ranks. It was necessary to calculate the statistics by 'hand', using a spreadsheet package. The Spearman correlation coefficient is easier to compute, as it is a simple comparison of the magnitude of disparities between two sets of ranks and can easily be calculated by using the formula in a spreadsheet. The Kendall correlation coefficient is more demanding to calculate, as it measures the 'probability of concordance minus the probability of discordance (Daniel, 1978, p. 307), and requires manually establishing the direction of differences in ranking for each pair of observations in the sample. The important advantage of the Kendall statistic is that it can be used to calculate the partial correlation coefficient. This is used to check if the correlation between two variables is genuine or results from the fact that both variables are actually correlated with a third variable. In calculating the partial correlation coefficient the influence of the chosen third variable is removed, allowing the determination of whether an independent, significant association exists between the two original variables. In this research I made use of both measures of association, although all reported statistics are only of Kendall correlation coefficients. Spearman correlation coefficients were calculated for all variables (see Appendix A), allowing the identification of significant associations and reducing the burden of computing Kendall statistics. All associations of interest, and all tests for the influence of third variables, were measured and tested for significance using the Kendall correlation coefficient.

In developing measures of organisational capability, it has been possible to use the data provided to the EPA to develop three sets of indicators. Historic capability measures are an attempt to make inferences about environmental management prior to the introduction of IPC licensing. I have identified two different kinds of static organisational capability that are required by the IPC legislation and that firms were not previously expected to demonstrate. Technical capability in pollution prevention and reduction technology, over pollution control and treatment is measured using five years of data on environmental projects, submitted to the EPA annually. Managerial capability in environmental management for delivering both control and continuous improvement of the firm's environmental impact is measured using qualitative criteria to assess the strength of the firm's routines. Dynamic organisational capability is also measured in this way. Analysis of the data collected using these indicators and statistical tests of association, will examine the role of organisational capabilities in the sector's response to a changed regulatory regime focussed on the promotion of technical change.

MEASURE	ACTIVITY MEASURED	USED TO SHOW
HISTORIC CAPABILITY MEASURES		
LOCN	Stringency of regulation prior to IPC licensing.	Influence of regulatory environment.
BATNEEC	Compliance with air and water BATNEEC standards	Level of investment in environmental technology.
GW	Presence/absence of contaminated groundwater from past environmental incidents.	Routines for effective environmental control. Inferred static technical capability
TIME	Time taken to provide the EPA with full and complete IPC application.	Level of codified environmental knowledge. Inferred static managerial capability.
TECHNICAL CAPABILITY IN CLEANER TECHNOLOGY		
CT	% firm's total projects (from licence application to 2000) that are cleaner technologies.	Static technical capability in cleaner technology.
WET	% firm's total projects (from licence application to 2000) that are end-of-pipe technologies.	Static technical capability in abatement technology.
STC	Projects of a given type account for >20% share of firm's total projects, > average share for all firms.	Specialisation and path-dependency in technical knowledge
CR	% firm's total projects (from licence application to 2000) that are chemical route change.	Capabilities for sophisticated process development work.
List I/II	Score assigned on strength of firm's pursuit of List I/II elimination.	Capabilities for challenging, environmentally-driven process development projects.
PD	Score assigned on strength of process development function.	Capabilities for process development.
ENVIRONMENTAL MANAGEMENT CAPABILITY		
SYSTEMS	Score assigned on strength of system of procedures and documentation	Static managerial capability in environmental management.
MEASURES	Score assigned on strength of development of data collection and measurable targets.	Static managerial capability in environmental measurement.
STRAT-DEVT	Score assigned on strength of routines for continuous environmental improvement.	Dynamic capability in strategic development for environmental management.

Table 5: Summary of measures of capability

Organisational Capability in a Firm-Specific Context

The indicators developed above will allow for the measurement and cross-comparison of all 16 firms in the selected cohort, leading to an analysis of the role of organisational capabilities in firms' response to a changed regulatory environment. In addition, it is the aim of my thesis to explore questions around the origins, significance and contingent nature of capabilities. Because of the complex and embedded nature of organisational capabilities I selected the case study approach. Stake defines case study research as 'not a methodological choice but a choice of object to be studied' (1994, p. 236), which may be studied using quantitative methods, qualitative methods or a combination of both. Yin (1993) sees it as being particularly appropriate where there are multiple sources of evidence but it is difficult to distinguish the issue to be studied from the context within which it is located.

> The essence of competences and capabilities is embedded in organisational processes of one kind or another. But the content of these processes and the opportunities they afford for developing competitive advantage at any time at any point in time are shaped significantly by the assets the firm possesses (internal and external) and by the evolutionary path it has adopted/inherited. Hence organisational processes, shaped by the firm's asset positions and moulded by its evolutionary and co-evolutionary paths explains the essence of the firm's dynamic capabilities and its competitive advantage (Teece et al., 1997, p. 518).

Negotiating Access

Negotiating access was a lengthy process and required careful management. The difficulty comes from the sensitivity of the issues. The research is sensitive for three reasons. Firstly, the industry has come under a lot of pressure because of its public perception as a major polluter and companies can be uncomfortable about discussing environmental performance. Secondly, the relationship between the industry and the EPA is a very recent one as the EPA was only established in 1992 and the IPC licensing process began in 1994. This relationship is still being developed and negotiated and I believed that the industry might find it threatening for this relationship to be examined before it is fully established. The third and most significant issue is that information on clean technology, especially if it leads to cost savings, may be commercially sensitive. No commercially sensitive information was discussed in the course of the case study visits. The director of the Irish Federation of Pharmaceutical and Chemical Manufacturers advised that:

> The industry is fairly open. If it is commercially sensitive they will not tell you and if they have done something in their process which made it cheaper, which a lot of clean technology can do, they will not tell you. Not if you publish it, because somebody else might take it up ... It's standard within the industry, for competitive reasons.[66]

I believe that these were not significant factors in gaining access because the focus of my research is not on evaluating the compliance record or environmental impact of the industry. The industry itself has adopted a strategy of being more open about its operations and in general welcomes the opportunity to demonstrate its commitment to innovation in environmental technology. Some of the points above raise the question of researcher independence. There is some dispute in the qualitative methodology literature on this issue. Buchanan et al. (1988) recommend providing transcripts and draft copies of work as a way of building trust, as well as a way of maintaining the research relationship after the field work is complete. Bryman (1988) believes that this allows companies the right of censorship and compromises the independence of the researcher. I have talked to an industry member who has had experience of being quoted out of context from a confidential conversation. He felt that the measures outlined by Buchanan would go a long way to building confidence. One of the measures to ensure trust taken in this research was that approaches to some of the case firms were made through an industry member. In all cases firms were given information on the approach of the research, the areas that would be covered in the research, making it clear that the focus was on environmental management and understanding the new licensing, not environmental compliance. Assurances were made to all the case firms about confidentiality and the provision of drafts and transcripts.

Ayella (1993) warns about the dangers of 'sanitisation or impression management' (p. 111) when researching organisations subject to pressure from public perception. She advises that such organisations may use researchers' findings in any 'stigma

[66] Interview: Matt Moran, Director, Irish Pharmaceutical and Chemical Manufacturers Federation, June 1997.

contests' (p. 121) over the acceptability of behaviour that they might be engaged in with society. This can affect research on many levels, including access, analysis and the perceived credibility of the research. On balance the need to provide reassurance to companies in exchange for access is paramount. Furthermore the right to check work for accuracy is not the same as a right to veto. Being aware of the possibility that firms may have an interest in compromising my independence was a sufficient counterweight.

Case Selection

The analysis of the cohort of 16 companies provided information required for case selection (Yin, 1993). The case study sample was deliberately constructed so as to maximise the opportunities for learning through cross-case comparison. Yin (1994) suggests that the advantage of multiple case study analysis (over single case) is the increased robustness of the results, which in turn strengthens the credibility of the research and enhances the generalisability of the theoretical propositions developed. 'Cases, like experiments, are generalisable to theoretical propositions and not to populations or universes' (Yin, 1994, p. 10). Cases should be selected so as to be either predictably similar or predictably different. Yin (1993) suggests selecting a mix, beginning with exemplary cases, which provide strong examples of the issue being researched. He advises testing for alternative hypotheses, either by (i) by developing a measure of 'mutually exclusive proof', data that can only confirm one of the hypotheses or (ii) including potentially disconfirming cases in the sample. Maxwell (1996) offers a number of choices for the sample composition: (i) representative or typical cases; (ii) the full range of possible cases; (iii) critical cases; (iv) controlled comparison cases. Stake counsels selection of 'cases that seem to offer an opportunity to learn' (1994, p.243), bearing in mind the need for balance and variety. With these recommendations in mind, the case study research concentrated on firms selected from the top and bottom of the firms as ranked on environmental management indicators (see chapter seven, table twelve). It was intended to include a firm from the middle of the rankings - firms that had evidence of developing but not yet established routines for environmental management - but the firm that had agreed to be included in the research withdrew from the study at a late stage and it was not possible to secure a replacement.

Pharma P has demonstrated a very strong commitment to environmental management and has integrated environmental concerns into operations from the beginning of it operations. The plant has been recognised with environmental management awards, and was selected as pilot firm for the EU's environmental management audit scheme. Interviews, lasting 90 minutes each, were conducted with the CEO and the manager for health, safety and environment, on 28 June 1998.

Pharma C was suggested to me as a firm that was not always strong in the area of environmental performance but had made significant improvements in recent years. Interviews, lasting 60-90 minutes each, were conducted with the environmental manager, the senior process development chemist and a chemical production engineer on 3 July 1998. I was also shown around the plant.

Pharma K is a long established, Cork firm with a precautionary approach to environmental management, and a history of poor community relations because of emissions problems. Interviews, lasting 60 to 90 minutes each, were conducted with the environmental manager, the chemical engineer in charge of developing the solvent recycling plant, and a senior process development chemist on 19 August 1998. I was also shown around the plant.

Pharma G has won awards for environmental management and clean technology and the parent company has taken a very proactive role in committing itself to environmental targets. the plant has a strong process development capability. However, there were long delays in the IPC licensing process and the plant has a history of poor community relations because of emissions problems. An interview, lasting 90 minutes, was conducted with the environmental chemist on 20 October 1998.

Pharma L has a strong process development capability and a history of pollution prevention through chemical route changes. The plant struggled to meet the conditions of its IPC licence, despite making a large investment in abatement technology. Interviews, lasting 90 minutes each, were conducted with the environmental officer and a process development chemist on 5 September 1998 and 15 October 1998. I was also shown around the plant.

Case Study Interviews

Interviewing can take three forms. Structured interviewing is where the questions are closed, and always presented in the same order. In some cases the answers may only be selected from a defined range. This type of interviewing is often used to gather data for quantitative analysis. Unstructured interviewing is where the questions are carefully posed in an open way, in order to generate as much response from the subject as possible. The interviewer does not follow a predetermined sequence but tailors her questions to the subject's responses. This type of interviewing is often used in inductive research where the researcher is not aiming to test prior theoretical propositions. Semi-open interviewing is flexible but has the structure of a prepared interview guide. This lays out the questions to be covered, but the sequence is determined during the course of the interview. Miles and Huberman (1994) advise that increased structure has the advantages of a more efficient use of time, increases cross case comparability and allows the interviewer to make use of the background knowledge she has already developed. On the other hand Michael Piore found in his experience of doing qualitative research in economics that

> most people had a story to tell. The interviewees used my questions as an excuse for telling their stories ... Either I let the respondent tell his or her story ... or else I forced him or her to treat the questions seriously and to give me a codable response to each item. If I took the latter approach, the respondents soon lost interest in the project and began to concentrate on getting through the questionnaire ... In this process, they often provided misinformation in order to avoid an anticipated follow-up question (Piore, 1979, p. 560).

My own approach to interviewing was semi-structured, beginning with broad, very open questions and as the interview progressed moving to gradually more specific areas, based on the areas of interest developed from analysis of the EPA files to provide jumping off points. This approach is suggested by Patton (1990) who advises that interviewing people on their knowledge can be threatening and suggests beginning the interview with non-controversial, descriptive questions, which facilitate building a rapport and allow the subject to gather their thoughts before answering detailed questions. He suggests that setting questions on knowledge of past events in a concrete context, such as providing instances of past events, can make such questions less threatening, and significantly improve the quality of their recollections. My intention was to let the subject tell his 'story', only using the interview guide to check that all areas have been covered and to follow up on any omitted area. The weakness is that the subject's story may be only tangentially, and not directly, related to the issues I explore; for example, in some cases subjects had a lot to say on the company's role as a good environmental citizen or on the relationship between the industry and the EPA. A well-prepared interview guide, with questions relating to specific areas of interest, was used to guide the subject back onto more directly relevant areas.

Within each company I interviewed the person responsible for environmental matters, usually the environmental manager. There were supplementary interviews with representatives from production, engineering and process development. Each case study visit took approximately half a day. The general format of the interviews was that the following areas were covered:

a) The firms' experience of IPC licensing; abilities required to get licensed; changes required to comply with IPC; speed of response.
b) Pollution prevention technology approach used within the company; influence of knowledge/past experience on pollution prevention technology; length of time the firm has been involved in pollution prevention technology; evolution of environmental technology within the firm; performance of Irish plants relative to

other plants within the company; organisational approach used by firm to develop technology; level of internal expertise; extent of external assistance

c) Organisational factors that support environmental performance; information available for decision making; training in environmental issues; commitment: general manager; environmental officer; line responsibility; HQ; culture with respect to TQM; continuous improvement; resource efficiency

d) Information on specific projects: how many projects have been implemented; type of projects developed; impact in terms of waste reduction and experience.

Conclusion

The nature of organisational capabilities is firm-specific, context-dependent and based on the unique circumstances of firm learning and experience. This means that analysis requires detailed information on internal firm management. I have developed measures of capability, based on information reported to the regulatory authority. This supports comparative analysis of the role of organisational capabilities in the sector's response to new environmental regulations. The findings of this research are presented in chapter seven. Further analysis of questions around the origins, significance and contingent nature of capabilities is explored in qualitative, case study research. Chapter eight presents the case study findings. Analysis of all the findings is presented in chapter nine, where it can be seen that the combination of the two research approaches allows for a full exploration of both the development and the implications of organisational capabilities.

7: Findings from Measures of Organisational Capability Research

Introduction

In this chapter I present the findings of research on the impact on firms of a regulatory instrument designed to induce technical change and increase the adoption of cleaner technology. My analysis will use the evolutionary theory of the firm to analyse the response of firms in the Irish pharmaceutical sector to the requirements of the new IPC regulations. The results will show that firms are differentially able to respond as the regulators intend, and this difference is associated with differences in organisational processes for strategic development. The findings support the importance ascribed by the theory to the role of organisational capabilities in determining a firm's ability to effect the necessary technical change and to manage the adaptation to a changed external environment. A full analysis of these results and the case study research is presented in chapter nine.

Regulatory regime and the development of organisational capabilities

As discussed in chapter six, on the basis of the theoretical literature we can establish the hypothesis that the regulatory regime acts as an influence on the development of capability within firms. My ability to test this hypothesis is constrained by the lack of detailed historical data on internal firm environmental management. Measures of historic capability are inferred from information provided by firms as part of the IPC licence application. It can be seen from table six that there is a clear and strong relationship between the stringency of the pre-IPC regulation and the state of the firm's pollution control technology at the time of IPC licensing. There is a statistically significant correlation[67] between the location of a firm and the achievement of BATNEEC in both air and water: firms that were located in Cork (and therefore more stringently regulated) were more likely to have technology in place to meet the emission limit values prescribed by the EPA in the new IPC licences.

[67] The Kendall rank order correlation coefficient is 0.746, significant at the 99 percent confidence level.

- 7 of the 16 firms were compliant with both water and air BATNEEC at the time of IPC licensing.

- Of these 7 firms, 6 were Cork based firms; only one compliant firm had been regulated by a local authority other than Cork County Council.

- 9 firms had not complied with both water and air BATNEEC at the time of IPC licensing; only one of these firms had been regulated by Cork County Council.

Result 1: A stringent regulatory regime will achieve a higher level of compliance with regulation.

FIRM	LOCATION	WATER BATNEEC COMPLIANCE	AIR BATNEEC COMPLIANCE
Pharma C	CORK	✔	✔
Pharma H	CORK	✔	✔
Pharma K	CORK	✔	✔
Pharma F	CORK	✔	✔
Pharma I	CORK	✔	✔
Pharma A	CORK	✔	✔
Pharma B	CORK		
Pharma P	DUBLIN	✔	✔
Pharma E	DUBLIN		✔
Pharma M	SHANNON		✔
Pharma G	TIPPERARY		✔
Pharma D	KERRY	✔	
Pharma J	CLARE	✔	
Pharma O	DUBLIN		
Pharma L	WICKLOW		
Pharma N	DUBLIN		

Table 6: Firm compliance with BATNEEC standards at time of IPC licensing

Clearly regulatory environment had an impact on the environmental activity within firms. Is it possible for us to say that the regulatory environment was responsible for shaping organisational capability? Using information from the IPC licensing process it has been possible to develop inferred indicators that suggest the possession of environmental capability. The limitation is that it has not been possible to gain direct evidence of the organisational routines on which these capabilities are based, but only to infer their existence from the output measures reported to the EPA.[68] The absence of contaminated groundwater from past environmental incidents is suggestive of a static technical capability for effective historic environmental control. The time taken to provide the EPA with a full and complete IPC application is suggestive of the level of codified environmental knowledge, or managerial capability. There is a strong and statistically significant[69] correlation between the two measures of environmental capability. This suggests that these two measures, uncontaminated groundwater indicative of good environmental control and timely provision of information indicative of good environmental knowledge, are indicators or elements of an underlying environmental management capability. Figure two, below, charts the time to provide information for the eight firms without groundwater problems, compared to the times for the eight firms with evidence of groundwater contamination.

Result 2: Firms that demonstrate full and codified knowledge of their environmental and production systems are also likely to demonstrate effective environmental control.

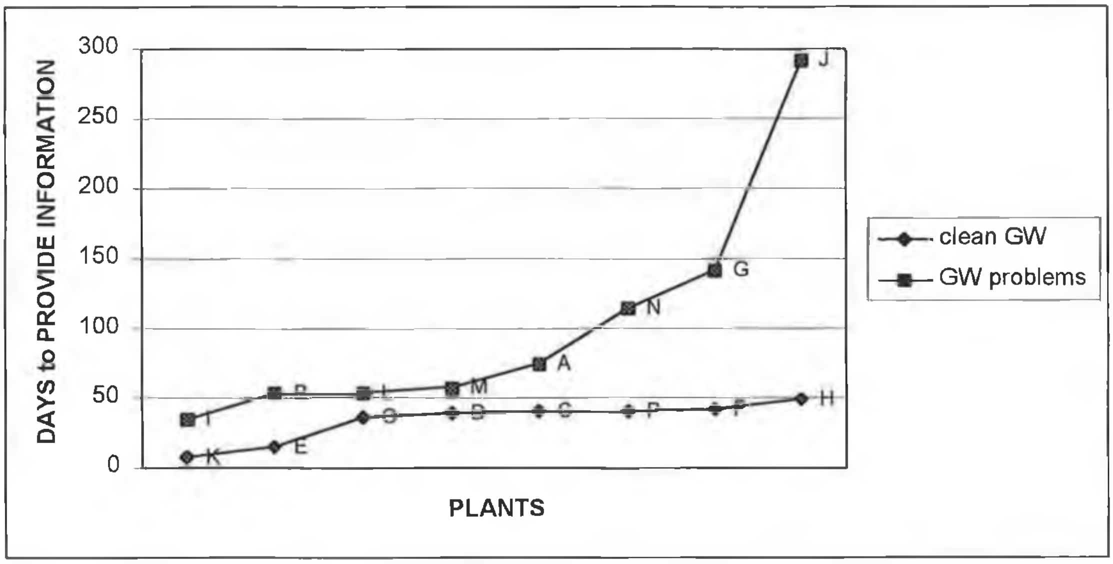

Figure 2: Time to provide information (days) and presence/absence of groundwater contamination

[68] In addition, qualitative evidence on the historic basis of organisational routines is presented in chapter seven.
[69] The Kendall rank order correlation coefficient between groundwater contamination and time to provide information is 0.598, significant at the 99 percent confidence level.

FIRM	LOCATION	BATNEEC COMPLIANCE	UNCONTAMINATED GROUNDWATER
Pharma C	CORK	✔	✔ 70
Pharma H	CORK	✔	✔
Pharma K	CORK	✔	✔
Pharma F	CORK	✔	✔
Pharma P	DUBLIN	✔	✔
Pharma I	CORK	✔	
Pharma A	CORK	✔	71
Pharma B	CORK		
Pharma D	KERRY		✔
Pharma O	DUBLIN		✔
Pharma E	DUBLIN		✔
Pharma M	SHANNON		
Pharma G	TIPPERARY		
Pharma L	WICKLOW		
Pharma N	DUBLIN		
Pharma J	CLARE		

Table 7: Firm historical environmental performance indicators

There is no statistically significant correlation[72] between the stringency with which the firm was regulated pre-IPC and the presence/absence of groundwater contamination. Firms that were able to demonstrate uncontaminated groundwater were equally likely to be located in or outside Cork. Nor is there any statistically significant correlation[73] between having environmental technology to BATNEEC

[70] Janssen's testing programme found evidence of groundwater contamination. The testing also determined however, that the contaminated groundwater was migrating onto the site, having been polluted elsewhere. For my purposes, the firm is therefore not considered to have contaminated groundwater.

[71] Cara's groundwater testing programme is on-going, and the conclusive report will not be submitted to the EPA until August 2000. However, both the company and the EPA inspector have given a high priority to the testing programme. Given that there is a concern on the part of the EPA, and in the absence of a definite report, I am assuming a result of contamination.

[72] The Kendall rank order correlation coefficient between location (i.e. located in Cork or located elsewhere) and groundwater contamination is 0.126.

[73] The Kendall rank order correlation coefficient between BATNEEC compliance and groundwater contamination is 0.378, significant at the 90 percent confidence level. However, as will be shown later, this association does not hold when the influence of other variables is removed.

standards and maintaining uncontaminated groundwater. Firms that have achieved BATNEEC are not less likely to have contaminated groundwater.

Result 3a: There is no association between being subject to stringent regulation and good environmental control.

Result 3b: There is no association between compliance with regulation by investing in environmental technology and good environmental control.

It can be seen from table eight that there is a wide variation (from 7 to 292 days) in the length of time taken by firms to provide information and achieve a complete IPC licence application. On average, Cork based firms achieved completion in a shorter time. This is because of very long times taken by three of the non-Cork firms. There is no statistically significant correlation[74] between the stringency with which the firm was regulated pre-IPC and the time required to provide complete information. There is also no statistically significant correlation[75] between having environmental technology to BATNEEC standards and the time required to provide complete information.

Result 4a: There is no association between being subject to stringent regulation and the completeness of the firm's environmental knowledge.

Result 4b: There is no association between compliance with regulation by investing in environmental technology and the completeness of the firm's environmental knowledge.

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[74] The Kendall rank order correlation coefficient between location (i.e. located in Cork or located elsewhere) and time to provide information is 0.197.

[75] The Kendall rank order correlation coefficient between BATNEEC compliance and time to provide information is -0.255.

FIRM	LOCATION	BATNEEC COMPLIANCE	TIME
PHARMA K	CORK	✔	7
PHARMA I	CORK	✔	35
PHARMA C	CORK	✔	40
PHARMA F	CORK	✔	41
PHARMA H	CORK	✔	48
PHARMA B	CORK		53
PHARMA A	CORK	✔	75
PHARMA E	DUBLIN		15
PHARMA O	DUBLIN		36
PHARMA D	KERRY		39
PHARMA P	DUBLIN	✔	40
PHARMA L	WICKLOW		53
PHARMA M	SHANNON		57
PHARMA N	DUBLIN		115
PHARMA G	TIPPERARY		141
PHARMA J	CLARE		292

Table 8: Firm historical environmental performance indicators

The role of organisational capabilities in response to IPC legislation

The IPC licence system introduced in 1992 has the features identified by Porter and van der Linde (1995a) as being important for the stimulation of creative, resource efficient responses. The focus is on outcomes, as firms are encouraged to identify their own solutions. In addition to compliance with emission limit values firms are now expected to demonstrate a commitment to implementing pollution prevention technology and to show continuous improvement in environmental performance. The regulation contains elements identified by the evolutionary economics literature as being essential components of organisational capabilities: the introduction of procedures for environmental planning and management; the requirement to collect environmentally pertinent information; the focus on developing problem solving within the firm.

Technical capabilities for cleaner technology

As discussed in chapter six, in this study technical capabilities is measured using data on environmental projects collected from reports submitted by firms to the EPA. A classification was developed that categorises projects by area (production; cleaning; utilities; waste; management), technique (chemical route; process; operations; equipment; information) and outcome (reduction; recycling; treatment). A broader measure, cleaner technology uptake, was also developed: all projects that have an outcome of reduction or recycling are cleaner technologies, and the measure CT is the percentage of a firm's total projects that are cleaner technologies. The projects reported by a firm (over the period from the time of licensing to 2000) are taken to be a reflection of its technical capabilities.

Broadly, IPC legislation represented a change of emphasis from end-of-pipe environmental technology to cleaner production technology. Table nine gives the results of uptake of cleaner technology for each firm in the cohort. All firms have been able to implement some cleaner technology projects; however, firms differ in their ability to adopt cleaner technology projects. The EPA has signalled to firms that the least favoured solution is the introduction of abatement equipment to treat waste;

table ten shows that while some firms are making minimal (less than 10 percent of projects) use of this technology, other firms are much more heavily reliant (more than 30 percent).

Result 5: Firms are differentially successful in the take-up of cleaner technology solutions.

FIRM	CLEANER TECHNOLOGY	FIRM	CLEANER TECHNOLOGY
PHARMA D	83%	PHARMA I	75%
PHARMA H	83%	PHARMA A	73%
PHARMA E	80%	PHARMA N	70%
PHARMA P	78%	PHARMA L	70%
PHARMA C	78%	PHARMA F	64%
PHARMA K	78%	PHARMA J	56%
PHARMA M	77%	PHARMA B	55%
PHARMA G	77%	PHARMA O	47%

Table 9: Rates of adoption of cleaner technology[76]

FIRM	WET[77]	FIRM	WET
PHARMA P	4%	PHARMA E	16%
PHARMA D	7%	PHARMA G	19%
PHARMA C	8%	PHARMA I	19%
PHARMA M	8%	PHARMA L	24%
PHARMA H	11%	PHARMA F	26%
PHARMA A	12%	PHARMA B	33%
PHARMA K	12%	PHARMA O	35%
PHARMA N	15%	PHARMA J	36%

Table 10: Rates of reliance on end-of-pipe technology

[76] The figures in table 4 and 5 do not sum to 100 percent for each firm. As well as cleaner technology and end-of-pipe projects, firms may also have undertaken projects, relating to environmental management or information-gathering, that do not have a clear waste reduction/recycling or treatment impact. These projects are not included in either of these tables.

[77] Waste Equipment Treatment: percent of firm's total projects (from licence application to 2000) that are end-of-pipe technologies, that is waste treatment projects involving equipment changes.

Alternative Determinants

The difference between firms in take-up of cleaner technology could be a function of firm size. It could be argued that larger firms have an advantage, in access to capital and other resources, that makes it easier for them to adopt cleaner technology projects. This is not supported by the data as there is no statistically significant correlation[78] between firm size and the level of cleaner technology adoption.

Result 6: Larger firms do not have a higher take-up of cleaner technology solutions.

It could also be argued that the distribution of cleaner technology projects is affected by differences in timing of environmental investment. The argument is that BATNEEC compliant firms may *appear* to have a higher adoption of cleaner technology projects in the period considered by this analysis simply because they carried out their abatement projects before the remit of this study. Now these firms are in a position to divert resources away from abatement projects into cleaner technology projects. Non BATNEEC compliant firms are not avoiding cleaner technology projects because of a lack of experience or capability. They are just forced, by the demands of regulation, to focus more of their attention and resources on abatement (end-of-pipe) projects to ensure compliance. If it were true that regulatory requirements were the main determinant then we would expect to see the highest absolute levels of abatement projects in the group 'Non BATNEEC (air and water)' and the lowest in the 'BATNEEC compliant' group. However this is not supported by the data, as there is no statistically significant correlation[79] between the level of compliance with BATNEEC and the number of end-of-pipe technology projects being carried out in the firm.

Result 7: BATNEEC compliant firms do not carry out a greater number of cleaner technology projects than non-compliant firms.

[78] The Kendall rank order correlation coefficient between firm size (measured by employment) and the level of cleaner technology adoption (measured by the percentage share of total projects) is -0.26051.

[79] The Kendall rank order correlation coefficient between level of BATNEEC compliance (i.e. either fully compliant in both air and water, compliant in one medium only, or wholly non-compliant) and the level of reliance on end-of-pipe projects (measured by absolute number of projects) is -0.09.

Specialised Technical Capabilities

We have seen that firms differ in their take-up of cleaner technology. From the literature on organisational capabilities we would also expect to see differences between firms in the *type* of projects they are able to adopt. Given the influence of the cumulative and path-dependent nature of organisational learning on a firm's capability to exploit technical opportunities we would expect to see firms developing related projects, that is, a concentration or clustering within firms of projects of a particular type. The detailed analysis of the types of projects undertaken by firms, using the classification discussed in chapter six, shows that projects fall into 39 different categories, and that the number of categories of projects used by any one firm ranges from 10 categories of project to 22 categories of project.

> **Result 8: There are firm-specific differences in the type of cleaner technology projects adopted.**

In many of the firms we see clusters of related projects, that is, a firm pursuing a number of projects in the same area, using the same techniques. A firm is considered to have a cluster of cleaner technology projects where (i) more than 20 percent for a firm's total projects fall within one category and (ii) the percentage of projects in this category is at least double the average percentage for the cohort as a whole. An end-of-pipe cluster is where a third or more of the firm's projects are related to equipment for waste treatment. The table shows that some firms are developing projects in related areas, using similar technical skills and knowledge. Some firms have responded to the demands of the new legislation and are developing cleaner technologies; other firms are still heavily reliant on end-of-pipe solutions.

> **Result 9: There are firms that have specialised in projects drawing on the same techniques and in the same area of experience.**

FIRM	SPECIALISATION	% of FIRM'S PROJECTS	AVERAGE % In ALL FIRMS
PHARMA K	CT • PROD • CR [80]	40%	15%
PHARMA I	CT • PROD • CR	33%	15%
PHARMA L	CT • PROD • CR	33%	15%
PHARMA A	CT • PROD • EQUIP[81]	27%	11%
PHARMA C	CT • PROD • PROC[82]	24%	9%
PHARMA H	CT • UY • OPS[83]	25%	2%
PHARMA P	CT • UY • EQUIP[84]	22%	6%
PHARMA D	no specialisation	-	-
PHARMA E	no specialisation	-	-
PHARMA F	no specialisation	-	-
PHARMA G	no specialisation	-	-
PHARMA M	no specialisation	-	-
PHARMA N	no specialisation	-	-
PHARMA J	TRT • WST • EQUIP[85]	36%	18%
PHARMA B	TRT • WST • EQUIP	33%	18%
PHARMA O	TRT • WST • EQUIP	35%	18%

Table 11: Specialised technical capability (STC)

Managerial capabilities

As a condition of a firm's IPC licence the EPA requires it to show the development of an environmental management system with measurable objectives and targets supported by management procedures and documentation. The development of the Measures and Systems indicators was discussed more fully in chapter six. Essentially both these indicators are scores assigned on the basis of evidence of routinised

[80] Cleaner technology projects in production, involving chemical route changes.
[81] Cleaner technology projects in production, involving chemical route changes.
[82] Cleaner technology projects in production, involving process changes.
[83] Cleaner technology projects in the area of utilities, involving operations changes.
[84] Cleaner technology projects in the area of utilities, involving equipment changes.
[85] Waste treatment projects involving equipment changes.

processes within firms. Firms with a high score (3 or 4) are those where the processes are established, smooth-running and integrated into the firm's environmental management, in some cases with external validation through either the commendation of the EPA or accreditation to the demanding European EMAS[86] standard. Firms with a low score (0 or 1) have little or no evidence of the use of measures or systems and may have been censured by the EPA for their lack of achievement. Firms with a moderate score (2) are firms where there is evidence that the required processes are being introduced and developed. It can be seen from table twelve that firms differ in the extent to which they have successfully introduced the managerial changes required by IPC licences.

Result 10: Firms are differentially successful in the implementation of organisational processes for environmental management.

The indicator STAT-DEVT is based on evidence of search routines, or processes to achieve the development of the firm's capabilities, both technical and managerial, in cleaner technology in order to meet the demands of IPC licensing. These routines include reconfiguration of organisational processes (such as co-operation between Manufacturing and R&D); formal use of inter-disciplinary problem-solving; established strategic planning and review systems. Scores are assigned on the basis of evidence of routinised processes within firms; a high score indicates established routines, a low score indicates little or no evidence of routines. Again, it can be seen from table twelve that firms also differ in the extent to which they possess dynamic capability for environmental strategic development.

Result 11: Firms differ with respect to the possession of routines and capabilities for environmental problem-solving and strategic development.

[86] Environmental Management Audit Scheme

FIRM	SYSTEMS	MEASURES	STRATEGIC DEVELOPMENT
PHARMA H	4	4	4
PHARMA P	4	4	4
PHARMA C	4	4	4
PHARMA I	3	3	3
PHARMA D	2	3	4
PHARMA K	3	2	3
PHARMA A	1	4	2
PHARMA E	1	3	2
PHARMA M	2	2	2
PHARMA F	2	1	2
PHARMA L	2	1	1
PHARMA N	2	0	1
PHARMA G	1	1	0
PHARMA J	1	1	0
PHARMA B	0	1	0
PHARMA O	0	0	0

Table 12: Scores for measures of managerial capability

Relationships between technical, managerial, static and dynamic capabilities

There is an association between static managerial capabilities and dynamic capability. There is a very high, statistically significant correlation between the existence of the dynamic capability for environmental strategic development and the development of environmental systems, as well as between the existence of the dynamic capability and the development of environmental measures (table thirteen).

Firms that have been able to develop routines for environmental systems have also been successful in developing routines related to measures and targets. The two sets of scores are correlated at a statistically significant level. However, calculation of partial correlation coefficients shows that this is due to the strong association of both indicators with the strategic development indicator; the indicators for SYSTEMS and

MEASURES have no association independent of their association with the STRAT-DEVT indicator of dynamic capability.

Result 12: Firms with dynamic capability are more likely to have been successful in the development of static managerial capabilities.

VARIABLES	LEVEL OF ASSOCIATION	DEGREE OF SIGNIFICANCE
SYSTEMS ↔ STRAT-DEVELOPMENT	+ 0.7638	99%
MEASURES↔ STRAT-DEVELOPMENT	+ 0.7136	99%
MEASURES↔ SYSTEMS	+ 0.5758	99%
MEASURES↔ SYSTEMS | STRAT-DEVT	+ 0.0679	-

Table 13: Kendall rank order correlation coefficients

We can also see an association between static technical capabilities and dynamic capability. Firms that show evidence of a dynamic capability for environmental strategic development were more likely to show evidence of technical capability in cleaner technology (as measured by the percentage of total projects). There is an association between managerial capability in respect of environmental measures and systems and cleaner technology capability, but again calculation of the partial correlation coefficient shows that this association does not hold independently of the influence of the dynamic capability for strategic development. Similarly there is an association between dynamic capability and the development of specialised technical capability (STC). Firms that have a high score for dynamic capability are more likely to have leveraged their skills and experience across a series of related projects, indicating a strong, specialised capability for a particular cleaner technology approach.

Result 13: Firms with dynamic capability are more likely to have been successful in the uptake of cleaner technologies.

Result 14: Firms with dynamic capability are more likely to have developed specialised technical capabilities.

VARIABLES	LEVEL OF ASSOCIATION	DEGREE OF SIGNIFICANCE
CT ↔ STRAT-DEVT	+ 0.6812	99%
STC ↔ STRAT-DEVT	+ 0.6333	99%
CT ↔ SYSTEMS	+ 0.4719	99%
CT ↔ SYSTEMS | STRAT-DEVT	- 0.1026	-
CT ↔ MEASURES	+ 0.6199	99%
CT ↔ MEASURES | STRAT-DEVT	+ 0.2609	-

Table 14: Kendall rank order correlation coefficients

It might be expected that firms with strong process development capabilities (PD) would be in a better position to achieve the technical change required by IPC licensing. However, as seen in table fifteen, there is no statistically significant correlation between the strength of a firm's process development function and the percentage of reported projects that are cleaner technology projects. Similarly, there is no statistically significant correlation between the strength of a firm's process development function and the pursuit of List I/II projects. There is however a statistically significant correlation between possession of organisational capability for problem solving and strategic development and List I/II project adoption. As might be expected, there is a statistically significant correlation between the strength of the process development function and the level of work done on chemical route changes (CR). There is no statistically significant correlation between the possession of routines for environmental strategic development and the level of chemical route change projects.

Result 15: Firms with process development capability are not more successful in the uptake of cleaner technologies.

Result 16: Successful uptake of projects to reduce use of environmentally harmful substances is associated with dynamic

environmental capability and is not associated with process development capability.

Result 17: Successful uptake of chemical route change projects is associated with possession of process development capability, and is not associated with dynamic environmental capability.

VARIABLES		LEVEL OF ASSOCIATION	DEGREE OF SIGNIFICANCE
PD	↔ CT	- 0.0412	-
PD	↔ List I/II	+ 0.0645	-
PD	↔ CR	+ 0.4503	99%
CR	↔ STRAT-DEVT	+ 0.1780	-
List I/II	↔ STRAT-DEVT	+ 0.7043	99%

Table 15: Kendall rank order correlation coefficients

The results presented above are suggestive of the importance of a dynamic capability for the development of new static technical and managerial capabilities within firms to meet the requirements of a new regulatory regime. The evolutionary theory of the firm identifies the development of capabilities as being cumulative and path-dependent, suggesting that in those firms with a strong dynamic capability for environmental strategic development, the development of the dynamic capability will have preceded the introduction of the IPC regulations. The evolution of the dynamic capability will be explored in the case study research presented in chapter eight, but it is also possible to look for any association between the historical inferred capability indicators and the dynamic capability indicator.

From the IPC licence applications it was possible to infer two measures of historic capability, namely uncontaminated groundwater (GW) indicative of good environmental control and timely provision of information (TIME) indicative of good environmental knowledge. As discussed above, there is a strong and statistically significant correlation between the two measures of environmental capability, suggestive of an underlying 'environmental management capability'.

These two indicators do not have a strong association with the dynamic capability indicator (STRAT-DEVT). The correlation between the two historic indicators holds independently of the influence of the dynamic capability. There is no statistically significant association between the time to provide information and the possession of dynamic capability, once the influence of the groundwater indicator is removed. However, firms with uncontaminated groundwater are more likely to demonstrate evidence of a dynamic capability of environmental management (controlling for the influence of the TIME indicator).

VARIABLES			LEVEL OF ASSOCIATION	DEGREE OF SIGNIFICANCE
GW	↔	STRAT-DEVT	+ 0.5250	99%
TIME	↔	STRAT-DEVT	- 0.3958	95%
GW	↔	TIME	+ 0.5984	99%
GW	↔	TIME | STRAT-DEVT	- 0.4997	99%
TIME	↔	STRAT-DEVT | GW	- 0.1198	-
GW	↔	STRAT-DEVT | TIME	+ 0.3916	95%

Table 16: Kendall rank order correlation coefficients

The possession of a dynamic capability for environmental management is strongly correlated with compliance with BATNEEC standards (table seventeen). Correlation is not the same as causality and the strong correlation between BATNEEC compliance and the dynamic capability indicator may be spurious, in that the true association may be of both of these variables with a third, so far unidentified, variable. If there is a causal relationship underlying this correlation, it is not possible to identify directly the direction of causality, that is, to identify which variable is the cause and which the effect. It may be that the process of achieving BATNEEC compliance influenced the accumulation of learning and experience within the firm and led to the development of a dynamic capability for environmental strategic development. Alternatively, it may be that those firms that possessed a dynamic capability for environmental management were in a better position to achieve BATNEEC compliance.

Although causality cannot be tested for directly, it is possible to examine related variables:

- The correlation between LOCN and STRAT-DEVT is not statistically significant (table seventeen) and there is therefore no support for the argument that being stringently regulated promotes the development of dynamic capability.
- There is a statistically significant correlation between strong STRAT-DEVT and uncontaminated groundwater (table sixteen), but there is no such association between BATNEEC compliance and GW (table seventeen).
- There is a statistically significant correlation between strong STRAT-DEVT and development of managerial capabilities for environmental systems and measures (table thirteen), but there is no such independent association between BATNEEC compliance and managerial capability development (table seventeen).
- There is a statistically significant correlation between strong STRAT-DEVT and higher levels of cleaner technology adoption (table fourteen), but there is no such independent association between BATNEEC compliance and cleaner technology adoption (table seventeen).

However, while the majority ($^5/_7$) of BATNEEC compliant firms have established routinised processes (scores of 3 or 4) for environmental strategic development there are firms ($^2/_7$) that have achieved BATNEEC compliance and demonstrate a limited strategic development capability (STRAT-DEVT scores of 2). Similarly, while the majority ($^6/_9$) of firms that have not achieved BATNEEC compliance show little or no evidence of dynamic capability (STRAT-DEVT scores of 0 or 1), there are firms in this group with evidence of developing ($^2/_9$ firms with STRAT-DEVT scores of 2) and strongly established ($^1/_9$ firm with STRAT-DEVT score of 4) dynamic capability.[87] Clearly possession of a dynamic capability for environmental management is neither necessary nor sufficient for BATNEEC compliance.

There is a strong and direct association between possession of dynamic capability and being able to respond to the demands of IPC regulations through the development of static managerial and technical capabilities. There is no such association between achievement of BATNEEC compliance and IPC compliance. This suggests that the possession of dynamic capability has a more central significance than the past experience of regulatory compliance with technology standards in determining the ability to respond to changes in environmental regulatory regime. In the next chapter, more in-depth, qualitative research in five selected case firms will explore the origins and significance of organisational capabilities.

VARIABLES	LEVEL OF ASSOCIATION	DEGREE OF SIGNIFICANCE
BATNEEC ↔ STRAT-DEVT	+ 0.6047	99%
LOCATION ↔ STRAT-DEVT	+ 0.3024	-
BATNEEC ↔ GW	+ 0.3780	95%
BATNEEC ↔ GW | STRAT-DEVT	+ 0.0892	-
BATNEEC ↔ TIME	- 0.2552	-
BATNEEC ↔ SYSTEMS	+ 0.6078	99%
BATNEEC ↔ SYSTEMS | STRAT-DEVT	+ 0.2838	-
BATNEEC ↔ MEASURES	+ 0.5825	99%
BATNEEC ↔ MEASURES| STRAT-DEVT	+ 0.2705	-
BATNEEC ↔ CT	+ 0.2552	-

Table 17: Kendall rank order correlation coefficients

[87] The plants selected for case study research, presented in the next chapter, are drawn from the two largest groups: plants that are BATNEEC compliant with have evidence of capabilities for strategic development and plants that are neither BATNEEC compliant nor show evidence of strategic development capabilities.

8: Evolution of Organisational Capabilities – Findings of Case Study Research

Introduction

The findings on the cohort of 16 companies, outlined in chapter seven, suggest that environmental strategic development was the key dynamic capability underpinning firms' success in adapting to the IPC regulatory environment. Information from the full cohort research was used to select a group of five case firms whose environmental management performance covers the spectrum of observed performances. This facilitates cross-case comparisons that bring out the key features being researched.

Each case study is presented under unique headings that reflect the particular features of interest of that case. Broadly, in each case there is an assessment of the evolution and influence of the firm's organisational capabilities. Information is presented on specific cleaner technology projects, and on the development of environmental management. The nature of the firm's relationship with the regulator, with parent company and with external sources of advice is assessed. In each case evidence of routines for problem-solving and strategic development is examined. An assessment is made of the connections between the environmental management function and the firm's overall strategic goals.

The case study research presented in this chapter establishes the relationship between environmental regulation, knowledge, past experience and the evolution of environmental capability in a few firms, selected because they best exemplify the theoretical propositions.

Case Study – Pharma P

Introduction

Pharma P is a subsidiary of one of Japan's largest pharmaceutical companies. Pharma P employs sixty people in its Dublin bulk pharmaceutical manufacturing plant, which commenced production in July 1988. The plant makes the active ingredients for four products. These products are sold under licence by other, larger pharmaceutical companies, and Pharma P supplies the active ingredients to these companies for completion into dosage form. It is common practice for Japanese firms to licence sales of their products outside Japan to companies who have stronger brand image and marketing capability in these markets.

WATER BATNEEC	AIR BATNEEC	GW	TIME
✔	✔	✔	40

CT	WET	SPECIALISATION	% of FIRM'S PROJECTS
78%	4%	CT • UY • EQUIP[88]	22%

SYSTEMS	MEASURES	STRATEGIC DEVELOPMENT
4	4	4

Table 18: Capability Indicators for Pharma P

Organisational Capabilities

Pharma P has a strong, integrated and broad-based array of environmental management capabilities founded on the strong dynamic capabilities for learning and planning that underpin all the firm's activities. Common to all decisions about future activity is the plant's concern to anticipate and plan change in a way that ensures that the change can be absorbed at a pace that allows for the maximum leverage of learning and experience within the firm. These deliberate efforts to 'lift the

[88] Cleaner technology projects in the area of utilities, involving equipment changes.

intellectual capacity of the organisation'[89] result in a wider array of strategic options in the future. Penrosian 'image' (Penrose, 1959) is the concept that the management's perception of future paths open to the company is a reflection of the plant's current capability set and past history. In Pharma P, the perception is that the plant benefits from taking up opportunities to maximise and exploit learning. Environmental management at Pharma P is not characterised by the development of any particular technical capability, but by the importance placed on integrative organisational processes for generating learning and deep understanding throughout the facility. This can be seen in the most recent plans for future expansion, and in the CEO's description of the development of environmental management at the plant.

Early Influences on Capability Formation

The plant has taken an integrated approach to environmental management from the beginning. The design of the physical plant had incorporated a high level of environmental protection. It is a reflection of the vision of the CEO who has been responsible for Pharma P from its conception, and was given free reign in the design of the physical plant design and management structures.

> When I joined [Pharma P] back in July 86 I spent four months living in Japan on my own. The mandate I had was 'look, come over, have a look at what we are doing, see what we are doing, and put together an organisation'. And what I did was in the last month really sat down and put the structures together and incorporated within that would have been the environmental aspect of the business.

The management approach at Pharma P is characterised by a strong sense of ownership and responsibility for their own future. This is a reflection of Japanese practice in the management of subsidiaries.

> In [Pharma P] it is not like a big American multinational, they will support you but you do it, that is the difference. Direction is sometimes lacking in Japanese companies, that is very much left to the team that is working on it. There is a clear policy on what you do, how you do it is your responsibility.

[89] All quotes in this case study, unless otherwise attributed, are from an interview with the CEO of Pharma P. 22.6.1998.

Environmental responsibility was integrated into the management structure of the new operation.

> What I was able to do was to put together a management structure and incorporated within that would have been the environmental aspect of the business ... By actually incorporating it in there and putting it in each department rather than saying 'I am responsible for the environment and you will help me to do it.' We don't actually have that, every department has its own environmental side to it.

The original organisational design aimed to diffuse environmental responsibility throughout all departments and represented an early commitment to the development of learning. Practices to support integrated responsibility and environmental learning opportunities included removing the distinction between environmental and production operators, and making sure that all operators have some experience of the environmental processes.

> People come in here one thing, and they change completely over the years, because it is a small team and they want to learn. Even with our operators, we move them around quite a lot and some companies would give their right arm for that, other companies the operators would say, well we want more money for doing that. Here if you tried to stop it you would have a problem on your hands.

Early proactive involvement in environmental management gave the plant an opportunity to take part in the EMAS pilot scheme. In 1989 the company won the 'Irish Good Environmental Management Award' and in 1990 the European Community and United Nations 'Award for Good Environmental Management' (Pharma P EMAS Statement, 1997). This led in 1992, to an invitation to become part of the pilot study for the EU Eco Management and Audit Scheme (EMAS). The company was the first pharmaceutical company in Ireland and the UK to be accredited to the BS7750 environmental management standard, in January 1996. The company was accredited to further standards, ISO14001 in March 1997 and EMAS in May 1997. The early recognition of their environmental management was a significant encouragement and validation of their approach:

> A good thing happened to us, back in 1989 we won the good environmental management award, in Ireland, and ... we went on the next year to win the European award, and that was a very good thing for

> the factory here. People knew that they were the best, and when you are the best what do you do? You try and hold onto it, and you don't hold on to draw, you hold on to excel. That has stood us in very good stead.

Cleaner Technology

The plant is rare in its use of a systematic approach not just for management of treatment and monitoring but also for planning and implementing waste reduction. The plant was able to use their involvement in the EMAS scheme, and the external expertise provided to develop a strong EMS, and most significantly a thorough understanding of the plant's environmental impacts through the development of the EMAS site profile. As part of the EMAS pilot the company prepared a site profile, which identifies and quantifies 'how does [Pharma P] interact with the environment' (Pharma P EMAS Statement, 1997). The understanding gained from the site profile has been crucial in driving the plant's programme of cleaner technology projects. By identifying and prioritising impacts it has encouraged the plant to explore projects in areas outside its past experience, developing new technical skills and wider future options. The CEO identifies 'routine setting of new environmental targets and objectives with subsequent evaluation of performance' (Sheerin, 1997) as one of the core elements of the plant's EMS.

> We would set ourselves objectives every year, the whole group would be involved in that, myself included. We would go through what we did in the last year. Unfortunately management sometimes concentrates on what is ahead and forgets to look back and see what did we do. We will have set ourselves pretty reasonable but demanding challenges for the next year. ... And sometimes we fail, but we record that as a deviation, that's life.

The systematic use of the site profile to plan future work, but also to review and consolidate past achievement has encouraged Pharma P to explore environmental improvement in many directions, not just in the area it was traditionally strongest in, environmental technology for containment. The plant has accumulated problem-solving knowledge capital, built on routines for problem identification, information gathering and solution generation. Using this capability the plant has undertaken projects in a broad range of areas: clean technology; solvent recovery; solvent recycling; resource use reduction; material substitution. The current projects being driven by the site profile are in utilities reduction projects and waste minimisation in production.

An energy profile carried out by the Clean Technology Centre (CTC) at the Cork Institute of Technology in 1996 has set the priorities for utilities reduction work. The plant has put in place cross-functional routines for developing a thorough understanding of site energy use and generating a broad range of solutions. A site Energy Group has been formed, with members from engineering, environmental management, environmental systems operators and R&D. Overall energy consumption (gas and electricity) per tonne of product was reduced by 33 percent between 1995 and 1996. The efficiency of gas use was improved by the installation of a new boiler plant and control system, completed in 1994. Plans for the future include a further 3 percent reduction from the condensate recovery project and waste heat recovery from incinerator. Electricity consumption per tonne of product was reduced by 8 percent between 1995 and 1996. Refrigeration plant use has been targeted, with the installation of a new brine tank in 1997, to improve the efficiency of the chillers. The WWTP aerators are being investigated, and their use may be reduced. Water meters were installed and a water mass balance calculated, in conjunction with advice from the CTC. This revealed that the site was a very high user of mains water. Pharma P has made changes to substitute well and rainwater for mains water use, where possible. The introduction of condensate recovery and a new cooling tower achieved a reduction in mains water use of 7.2 percent, as well as improved energy efficiency gains. Further water reductions of 20 percent are planned if it is possible to recycle extra cooling water through the new cooling tower system; this project has experienced some difficulties.

In the area of waste minimisation, in 1994 Pharma P undertook its first solvent elimination project, to explore the removal of List II solvents, toluene and methylene dichloride, from the production of nicardipine. This project is a good example of how management at Pharma P are prepared to undertake projects in areas outside its familiar activity and competences. Historically Pharma P has had limited opportunities to undertake process development projects. The company is not typically a start-up plant for the production of new products, but receives established products and technology from the parent company. The work of R&D has been confined to process optimisation (minor adjustments to process conditions) and exploration of recovery, and as the plant produces only four products, there are limited opportunities even for this type of work. The solvent elimination project involved collaboration between Pharma P, the parent company and the CTC in Cork. R&D at Pharma P in Ireland carried out the lab work, and successfully demonstrated solvent elimination in the pilot plant. However the changed route has not been implemented as yet. The company is undertaking a cost benefit analysis to assess the relative costs of FDA re-registration and Pharma P's customer will have to approve of the change.

Commitment to Develop Organisational Capability in Process Development

While the solution developed by the solvent elimination project may or may not be implemented, the plant sees the real achievement of the project as being in building capability and experience. This contributes to the plant's strategic commitment to create a process development capability at Pharma P. The plant has a direct relationship with its commercial customers (licensees) and works hard to maximise the value and therefore profitability of these relationships to the company. Although typically Pharma P has not been involved in process development, the CEO has recently taken the decision that expertise in this area is important, to maximise efficiency of production but also as part of the CEO's overall strategy for the evolution of the plant. In 1998 Pharma P opened its new Manufacturing Technology Building. It is intended that this will increase the involvement Pharma P have in R&D and process development: 'that is something which we are now facing up to … where we are heading at the moment is lift the intellectual capacity of our organisation and that is process development.' Pharma P are heading into a period of expansion, with a number of new products being introduced to the plant. The new group's function will include the improvement of existing products, including environmental impacts.

Process development work pursued for environmental goals, using external and corporate expertise, is cited by the CEO as having had a role in building the skills and experience within the plant that will now support a Process Development function. In the development of this facility the plant's capability for maximum learning is again expressed: 'What I have tried to do in this building is I have put a load of chemical engineers and a load of chemists in, in the belief that they can talk to one another, work together.'

A waste minimisation group was formed in 1997 to identify waste minimisation opportunities through process development, based on priorities identified in the site profile. The company feels that it is now that it has learning, experience and physical resources to make this initiative feasible. This is an area in which the plant will again be ahead of practice in the parent company, and Pharma P anticipates that this group will act as a corporate resource so that the benefits of their learning can be shared within the company. The change is driven by commercial reasons, to offer a better service to commercial customers: 'it is extremely important for us at each and every opportunity, and with my own staff I emphasise that point, for us to be more efficient.' Pharma P's strategy is to develop the plant's importance and competitiveness by developing its relationship with its commercial customers and upgrading the quality of the service they offer:

> If you take the evolution of a plant like ours: you are kind of a local manufacturer supplier; then you become a contact point for your customers and you add value to the system; then you start developing the directed approach of supporting your customers.

Role of External Help

Maximising the learning capability of the plant is central to the CEO's management strategy. Another commitment that the firm has made is to avoid the use of external consultancy. 'We try and avoid consultants ..., we try and do as much as possible ourselves.' For example the company did not use any external consultants in their preparation for ISO9000 or ISO14001 accreditation. The company draws a distinction between consultancy advice and accessing and internalising external knowledge. If they need external expertise they ensure that it is used as an opportunity for learning within the company.

> Where there are areas, what we do there is rather than sending out people to do these courses we would bring in the leaders, wherever they may come from, here. We will put in a bunch of maybe 10 people, people that may not have any great bearing on that but who would like to learn … So our competency is increasing all the time.

Pharma P is committed to accessing fundamental research in order to increase its environmental capability and has a policy of working with research institutes to increase knowledge of environmental technology. It is a founding member of The Clean Technology Centre at the Department of Chemical Engineering in Cork Institute of technology. It is a founding member of Questor, a research centre based at the School of Chemistry, The Queen's University of Belfast. Pharma P has worked with these and other institutes (such as the Environmental Science Department at Sligo Institute of Technology) to develop understanding and solutions to particular environmental problems.

Conclusion

A strong sense of ownership can be seen in both commercial and environmental management decisions that, while challenging in the short-term, are important for the plant's long-term development. The plant has a high awareness of its external (commercial and regulatory) environment and puts effort into planning. This has allowed it to anticipate changes such as IPC legislation. Importantly for a small company, it is then able to absorb new requirements at its own pace and according to a planned programme that allows it to maximise the learning opportunities associated with new developments. This attitude is partly a reflection of the self-directed management style, and the parent company management style.

> If you are working in the likes of SmithKline[90] and you are going to build a new plant, well before you know where you are you will have whole team of experts out there. We don't have that. But what is has allowed us to do, we have had to work harder, we have had to build up our own expertise in many areas that areas that people would not have

[90] US pharmaceutical MNC.

been qualified or trained on. That's actually good, it has added a little bit of excitement, and the knowledge base.

The company has a very good record of compliance. In 10 years of operation it has never received a complaint from the public. In records kept for the FDA it has recorded only one quality non-conformance. The plant has 100 percent compliance with the emission standards in their IPC licence.[91] A benefit and reinforcement of their environmental strategy has been the increased standing that it gives them within the corporation.

> The Japanese would not have had a very clear view on environmental issues. … They had on certain areas but not to the extent that we have now here. And in fact a lot of them now would be copying our systems. As well as the technology coming in we are actually exporting it out… For instance we didn't use any consultation on the ISO1400, or ISO9000, we did it all in-house. We are now actually giving this data to some of our sister plants around the world. And we would be seen by the parent company as being leaders in that area.

As well as having a commercial importance, competitiveness is important to maintain the plant's standing within the corporation and to ensure that the plant is selected to produce future products. The integrated nature of the plant's environmental capabilities is reflected in how they support and are supported by more general competitive capabilities.

> Don't worry about the competition outside … Worry about your own internal competition … We are here to try and bring them [the parent company] more business, more added value business, and that is what it is all about. Why should they give us something if we are not competitive?

[91] However, they have two technical breaches of their licence relating to equipment specification problems.

Case Study – Pharma C

Introduction

Pharma C is a wholly owned subsidiary of a Belgian pharmaceutical company which in turn is part of a US healthcare company. The Cork plant was bought from another company and production began in 1981. The plant is an organic synthesis bulk manufacturing plant, producing the active ingredients for a range of pharmaceutical products. The plant supplies other operations (60 percent of production) within the parent company, as well as third party companies producing under license (40 percent of production). The plant operates as a pilot plant for the introduction and refinement of new products and processes that have been developed by the Belgian R&D function. The plant expanded in 1992, adding an extra production building and increasing capacity by 100 percent. Further expansion plans were announced in 1999.

WATER BATNEEC	AIR BATNEEC	GW	TIME
✔	✔	✔	40

CT	WET	SPECIALISATION	% of FIRM'S PROJECTS
78%	8%	CT • PROD • PROC[92]	24%

SYSTEMS	MEASURES	STRATEGIC DEVELOPMENT
4	4	4

Table 19: Capability Indicators for Pharma C

Evolution of Organisational Capabilities

Like Pharma P, Pharma C has a strong, integrated and broad-based array of environmental management capabilities, founded on strong capabilities for identifying and managing change. The plant has processes for scanning the

[92] Cleaner technology projects in production, involving process changes.

environment and anticipating where the plant needs to be to meet future requirements. In comparison to Pharma P, environmental management is supported by strong corporate functions and this advance planning gives the plant the opportunity to obtain the necessary corporate approval and capital for upgrading the existing facilities and achieve a timely and competent response to change.

> The system for most multinationals like ourselves is would be to do what is called strategic planning, strategic is normally five, ten and fifteen year planning, so you are looking at those kind of time horizons. ... In a five year horizon what is being debated in first or second readings in Brussels now will probably be fully fledged directives in five years time. It takes three to five years to get a directive out of Brussels. So you are keeping an eye on that.
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> Looking at European legislation, the things that were happening, the company would have reacted and said 'we need to have something for this time horizon, we need to have these people'; they will have gone to corporate.[93]

Pharma C began to develop its environmental management systems in anticipation of the new regulations and established its first formalised Environmental Strategy in 1988.

> Environmental issues throughout Europe through the late eighties, early nineties really took off, exponentially ... Directives (we always monitor directives) out of Brussels started to change; the whole issue of sustainability started to slip into the agenda. Corporate, through the US and the EPA, started to drive programmes forward, ... It was really at that point that we started to formulate what would be today known as an environmental management system ... I started here in 1989 almost as a part of the company's direct response to the need to meet this challenge. ... The company was then responding to these changes and up to that point environment was just a component of Technical Services, with an operator running the waste treatment plant. You then had a fully fledged environmental section which was formed, completed if you like, in 1990/1991 ... It is when you have the environmental staff then we began to look at *real* environmental management systems as we understand them today.

In the short run the plant invested in air treatment equipment to meet the more stringent air emission limit values (ELVs) standards established under the Air

[93] All quotes in this case study, unless otherwise attributed, are from an interview with the Pharma C environmental manager, 3.7.1998.

Pollution Act of 1987. The strategy set internal standards for the new technology at 50 percent of the ELVs. The plant upgraded existing treatment equipment and installed new systems. The strategy ensured that the new technology was operational prior to the new air licences being issued in 1991, achieving Pharma C's objective of full compliance: 'We have never exceeded any licence parameter ever, we have always managed to get our equipment in before the deadline.'

Whereas Pharma P operated an integrated environmental management function from the very beginning, this is a position that Pharma C has evolved to. The environmental manager explicitly acknowledges that the current state of environmental management has evolved significantly from its initial abatement focus:

> The change has been I suppose in the early days the environmental, let us call it management system, on site consisted of air and water treatment; the waste handling got incorporated; then we went to licence reporting, data reporting, data logging data filing requirements; then we moved into an ISO-style system where environmental parameters get incorporated; … and then we started on the system where we incorporated them into the site management system.

This evolution pre-empted future regulations, being committed to in the 1988 Environmental Strategy, which in addition to short-run abatement goals, set long run pollution prevention goals: 'an on-going commitment to yield improvements was made and a long-term objective of eliminating chlorinated solvents was defined' (Pharma C IPC application, EPA files, 1994).

The parent company's corporate environmental systems have provided a strong framework for Pharma C's environmental systems. 'Initially then we had a document known as the Worldwide Environmental Affairs Guidance Document … It is a guidance document with codes of practice, environmental operations. And that was the initial system.' Since 1992 an annual environmental report is made to Corporate Management covering pollution prevention, regulatory compliance and leadership. In 1993 a two-year project involving a cross-functional team of 100 site managers world-wide established a set of pollution prevention goals for the corporation. As part of the parent company's commitment to US EPA reporting programmes such as the 60/40 convention, the Toxic Releases Inventory and SARA2, Pharma C were collecting and submitting environmental performance data on certain materials to the corporate environmental function.

> It was very useful from the point of view of developing our systems and our thought processes ... It gave us the system; we only had to expand it to include more materials subsequently. We went from the [parent company] global reporting system to preparing the IPC application ... and I think we did a good job.

Pharma C laid the foundations of their environmental capability during a period of high corporate attention and support.

> In the late eighties and early nineties environmental was one of the magic words. If you tagged the word environmental onto any project it was almost going to a green light [for corporate capital approval] ... Anyhow, in those days environmental was the focus; things were more or less approved by corporate quickly and efficiently. The environmental system, staffing levels were built then, the carbon plant was built, the wastewater treatment plant was upgraded and tweaked at. It is when you have the environmental staff then we began to look at *real* environmental management systems as we understand them today.

Since that time corporate priorities have changed: 'because the last 2 years [since 1996] ... FDA validation[94] is the new thrust for the corporation; so if it is not FDA and it is not validation, ... you have to wait for your money.' The parent company continues to develop its environmental management. This has evolved into the ECO 20/20 programme, 'a developing programme that focuses on proactive prevention as the driving force behind our environmental management. We intend to use this initiative as a tool to coordinate our long range environmental efforts and to better integrate environmental concerns into strategic planning of all our business operations' (parent company website).

[94] FDA validation refers to the process of US FDA inspection and approval of manufacturing practices, which must meet the FDA standards for Good Manufacturing Practice (GMP) as a requirement for selling into the US market. In the mid nineties the FDA required the adoption of more stringent cleaning practices. Validation was a particular focus for Pharma C because the company had not previously sold into the US market, and was seeking FDA validation for the first time.

Pharma C's environmental management has continued to evolve, but in a direction determined more by the requirements of IPC licensing and the nature of its internal capability than by corporate systems. 'The licence then required us to put in an environmental management system, so in effect our environmental management system at that time was still the [parent company] system, combined with the additional requirements of the IPC.' The plant had a positive experience of formal quality systems, ISO9000 and the Malcolm Baldridge Principles, and also favoured an accredited environmental management system given that

> in this industry, where there is a level of public concern and the whole public perception, better to have something that is independently verified than to be saying 'well we're doing it ourselves and we know you trust us'. We thought it was better to have a formal system.

At this time, 1994-1995, accredited environmental management systems were still being developed. The company investigated all the systems, pursuing the (now withdrawn) Irish standard IS310 and gaining accreditation to the international ISO14001 standard in 1997. The plant sees accreditation to the more demanding EMAS standard as 'the next stage.' Both Pharma P and Pharma C have used external quality and environmental management systems to support the evolution of their own systems.

The environmental manager refers to Pharma C's current position as being one of 'integrated site management'.

> We really now have what you would call integrated environmental management. It is quality, safety, environment and general site management are all assessed collectively, all the conflicts are assessed with the site management team and the appropriate departments are there. ... You make the options available to the management team and they decide what the company's objectives are for the coming year.

This integration works on a number of different levels. As the quote above shows, the environmental function forms one part of the site management functions. Also the environmental manager has a good knowledge of, and working relationship with, the whole operation. 'Environmental is a useful job in that I get to go everywhere, there is no door that I do not have access to, my swipe card opens all the doors, I can poke my nose into absolutely everything.' This integration can be seen in the operation of the continuous improvement programme (CIP). At any one time within the company there are ten CIP teams, made up of people from different levels and disciplines, each working on particular problem-solving brief. The system was introduced to promote quality, responsiveness and empowerment in improvement. Pharma C does not have a permanent waste minimisation team, but instead uses the CIP system to pursue specific waste minimisation projects.

> In the company here, through the whole CIP and empowerment system it is flexible ... If an operator comes up to me, and they have an idea to do something in the plant and there is a benefit, I will then go through the chain to get permission for that guy to maybe have half a day a week off from his shift work to work on whatever it is. That is very common here. And the guys like it because it gives them a bit of variety, so there is a benefit to the company. I get work done with additional resources that I do not have, with people who know what they are doing ... We have a lot of flexibility and good attitude and commitment, across a lot of the workforce.

Like Pharma P, this system promotes learning and involvement across the firm, although the system is more formalised in Pharma C. Furthermore the continuous improvement team process described above is not specific to the environmental function, but part of the plant's strategic plan for a flexible and responsive organisation. As well as environmental responsibility being diffuse across the organisation, the environmental function is seen as being fully integrated into the plant's strategic objectives and as having a responsibility in achieving those objectives. Many of the projects carried out have joint efficiency/environmental outcomes.

Cleaner Technology

Under the requirements of its IPC licence the plant now produces an annual Environmental Management Plan (EMP) and an Annual Environmental Report detailing progress against the EMP objectives. It can be seen from these that the plant is pursuing waste minimisation in many areas of the operation, supporting their belief that their 'philosophy towards cleaner technologies, waste minimisation and raw material substitution has evolved over the past decade' (Pharma C IPC application, EPA files, 1994). The plant is now pursuing waste minimisation in yield improvements, solvent elimination, improved cleaning procedures to reduce solvent use, and campaign length increases.

> We have now moved to where almost the monitoring, the waste treatment, the waste handling, the waste water, the air, that is almost incidental now we have been doing that for so long, It is just part and parcel now. Whereas in the early days the focus was on that, that now just happens, that runs, it works, it works very well, we are very pleased with it. We are now starting to work back up. The effect has been primarily driven by the EPA this time.

As the experience and knowledge within the environmental function, and the Cork plant, has grown, the plant has begun to work to integrate its environmental concerns with the work done in the corporate R&D function.

> In terms of our management system, the way it is changing from the focus on treating waste, air, water, back to a site management system. Now we have moved back to the point where those changes we have no control over on this site. We are a manufacturing facility, the processes are developed in Belgium. But we pushed ourselves up the chain and … we got through to them and … I have given a few presentations in Belgium on the principles of cleaner technology … We have given that presentation to the people in Belgium, to try and hammer home the message.

The plant is a founder member of the Clean Technology Centre (CTC). They have used the services of the centre in the development of a cleaner technology approach to environmental management. Their advice has been important in providing the environmental manager with the knowledge to influence the corporate R&D function to consider pollution prevention when developing chemical routes for new compounds.

Wastewater Treatment Plant Optimisation[95]: In 1991 Pharma C was considering a significant expansion of the wastewater treatment plant (WWTP). This was needed to deal with the planned 100 percent increase in production capacity. The plant was also committed to the elimination of chlorinated organic solvents, which would require increased quantities of substitute solvents and hence an increased load on the WWTP.

An alternative solution was suggested by R&D in Belgium, based on a visit to a competitor's plant. A programme of solvent use reduction would allow the company to handle the increased volume with its existing WWTP facility and level of effluent emissions. The deciding factor in adopting the alternative solution was the cost saving of avoiding the new investment.

The plant pursued a number of ways of reducing solvent use. R&D provided assistance in developing changes to cleaning procedures. Cleaning procedures are registered as part of a given drug's manufacturing process and so changes require approval, although this is simpler than for chemical route changes. All 54 cleaning processes were evaluated, and in all but one solvent substitution could be made. Another change was to production planning. By increasing the number of batches of a particular product made at one time (known as a campaign) the number of cleanings involved in preparing the production equipment for a switch to a different product could be reduced. Procedures for end of campaign cleaning were investigated, and a systematic protocol was developed to ensure that the minimum appropriate level of cleaning was used, depending on the vessel's next use. Process Engineering has carried out a project to optimise the layout of the WWTP itself. This has increased the volume of effluent that it can process, as well as decreasing the use of neutralising chemicals used by 60 percent.

The project encountered a setback when the plant began pursuing US FDA validation of its manufacturing processes, as the FDA have made changes to the cleaning protocols within the GMP guidelines, significantly increasing solvent required. The company is attempting to mitigate this impact through equipment changes developed by Process Engineering. The plant is installing a centralised cleaning unit for cleaning portable process equipment. This automated unit will use detergents instead of solvents; as well as cost-savings in solvent disposal, it will bring benefits in increased speed of cleaning, standardisation of practice and will meet the FDA requirements.

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[95] Some of the information on this project is taken from Clayton et al. (1999).

The goals for 1997 were (i) increase the number of batches per campaign from 3.4 to 4.0; (ii) reduce the number of cleanings from 201 to 190, despite a 20 percent increase in output. The goals were partially met: the use of 500,000 litres of solvent was avoided; the average number of batches per campaign was increased to 5.0; the number of cleanings however increased to 300 due to the FDA's increased cleaning standards. The solvent use reduction project is on-going, but the goals have been amended: 'the environmental requirement, instead of being a 10 percent reduction in solvent usage, was to minimise the increase in solvent usage, because we needed FDA approval to sell into our market. Without FDA approval, solvent usage becomes academic because we won't be using any solvent if we close down.'

Solvent Elimination: The plant launched a chlorinated solvent programme in 1988 to investigate the elimination of chlorobenzene, chloroform and dichloromethane (MDC) by 2000. This objective to eliminate chlorinated solvents was set as part of the parent company's public commitment to achieve elimination in advance of the deadline set by the Paris Convention.[96] Chlorobenzene was eliminated by 1994. Chloroform was used in four processes, with an annual consumption of 380 tonnes. Elimination was achieved by the end of 1996; new chemical routes for the four processes were developed by R&D in Brussels and successfully reregistered with the FDA. This goal was pursued as part of a corporate programme to eliminate chloroform in all plants.

MDC is used in three processes and the original target was to eliminate its use by 2000. This goal has been revised and the plant is not now pursuing MDC elimination as a priority. This is partly because usage is low - less than three tonnes p.a. or 0.25 percent of total solvent usage. Also, whereas there was a drive to eliminate chloroform in all the manufacturing plants, there is not the same pressure in the case of MDC. In most regulatory authorities in the world chloroform is considered to have a significant environmental impact, and is therefore commonly a Class I solvent. MDC is generally put in the lower Class III, but has been classed a Class I solvent by the Irish EPA since 1997.

[96] An international treaty, signed by the member states of the Council of Europe, under which signatories agreed in principle to the elimination of emissions of toxic and persistent chemicals, especially chlorinated solvents.

Toluene is a solvent widely used in pharmaceutical manufacturing, and has not been identified as problematic by other regulatory authorities, but the EPA has placed a priority on its reduction and elimination. Pharma C have eliminated toluene from one process but are reluctant to commit to further elimination in the three remaining processes. Toluene is a widely used solvent with few substitutes; in one of the chloroform eliminations Pharma C actually used toluene as a substitute for chloroform.

> The Irish EPA are the only ones pursuing it with any urgency, and corporate tends to deal with these things globally. Whereas *all* the manufacturing plants were coming back and saying chloroform has to go, we are the only company coming back and talking about toluene ... Unless the EPA had not highlighted it we would not have pursued it.

Yield Improvements: As well as bulk manufacture the plant is used as a pilot plant, with processes transferred from R&D in Belgium for small scale manufacture and process debugging before being introduced to the much larger (by a factor of fifteen) facility in Belgium. This means that the plant in Cork has developed a lot of experience in process development. A quarter of the projects reported to the EPA in the annual environmental management programmes are related to yield improvement work lead by this department; 'our major efforts in waste minimisation have focussed on yield improvements as this is one of the major cost drivers in the company's operations' (Pharma C IPC application, EPA files, 1994).

This programme is a relatively recent development, and reflects a strategic commitment to the enhancement of the Process Development capability, following a similar strategy to that in Pharma P. A decision was taken to move from trouble-shooting production difficulties to pre-emption of problems, changing the work of the department to focus on deeper understanding and therefore control of process parameters. The plan was supported by corporate resources to enhance the laboratory facilities, and by its good working relationship with corporate R&D. The increased understanding generated by this work is also applied outside the department, using processes for inter-disciplinary projects. Process knowledge was combined with the experience of Manufacturing to upgrade processes and technology.

Prior to 1996 the Process Development function's main priority was providing a trouble-shooting backup to production of existing compounds, but then 'changed philosophy to getting in front of the problems.' This was complemented by increased resources, and by 1998 the department was working entirely on new processes. This has been achieved by increasing the laboratory phase of the introduction, providing richer information to identify and remove wrinkles in the process parameters.

Manufacturing is involved in the project, using increased understanding and experience with the manufacturing personnel and equipment to implement improvements to the efficiency with which the process is operated in the plant. This work is done in cooperation with the Process Development function. One element of this programme was a continuous improvement group that was formed to look specifically at centrifuge equipment, an area of potential improvement that was identified through analysis of the process history. Another element is that the knowledge gained by the process development laboratory work is communicated to the process operators in the plant, giving them increased awareness of the critical watch points in the process.

The yield improvement programme had four main aims which integrate economic, environmental and quality goals: (i) achieve right-first-time product introduction; (ii) bring yields up to the targets established by R&D; (iii) identify and eliminate process problems and therefore costly (and environmentally significant) reworks; (iv) increase the precision of operations. The outcome of the programme has been tighter control of the process parameters and 'total control of the technology on site.'

Conclusion

The integration of environmental management into site management, coupled with the bottom-up involvement in problem-solving has led to a strong and diffused environmental responsibility within the plant that supports the overall strategic development of the plant.

The processes for inter-disciplinary co-operation on projects support a diffusion of environmental responsibility and problem-solving skills through the organisation. This has allowed the company to solve particular environmental problems using a combination of solutions. The goal of yield improvement was achieved by optimising process parameters (such as conditions of reactions), improving operator efficiency and upgrading technology. Another significant goal, solvent use reduction, was achieved using a number of approaches and involving different parts of the organisation: chemical substitution; production planning; cleaning processes; engineering changes.

The plant management is well aware of the importance of environmental management in securing the community's goodwill and 'licence to operate.' They have a good relationship with the local community, something they value and are keen to preserve. This relationship is the reason the plant has chosen not to install incinerator technology.

> It gives us less flexibility but we have a national school within about 100 feet of our northern boundary ... There is a whole string of really good environmental reasons why we should have an incinerator and I would be a huge supporter of them and I feel we should have one, and I live relatively close to this place ... However that is not the way the world works ... We will never actively consider one ... Purely on emotive reasons; on environmental reasons, economic reasons, cost-savings I would love one.

Environmental management is seen as contributing to competitiveness within the corporation. The plant has benefited from being able to use its own strong planning capabilities and the access to corporate resources to build environmental management: 'we are king of the heap, we were the first company [within the corporation] with ISO14001 registration, the first company with a carbon air abatement plant to meet TA Luft regulations'. The environmental manager has a high awareness of the role strong environmental management can play in supporting the competitiveness of the plant in relation to intra-corporation competition.

> You have to fight tooth and nail for everything you get. That is where the tangible benefits [of environmental management] come in. If the corporation announces they are building another $50m^3$ reactor capacity every bulk plant in the world goes after it because everybody wants to expand. Each company then fights and it is vicious and it is dirty. You do everything you can to get it. This is where you start hauling up: 'and look, we filled in all our corporate reports, we got everything in on time, we met all your requirements, we met all your targets, we have an IPC licence, we are 100 percent compliant, we have a great relationship with the local authorities. We have already got our planning application sorted out, give it to us we can start building tomorrow. Look at the tax situation here, look at the headcount, infrastructure, workforce, availability of new employees'. You throw everything into the kitty and fight very, very, very hard for every new product.

Case Study – Pharma K

Introduction

Pharma K was set up in 1975 to manufacture the active ingredient for the parent company's leading product which was for many years the most prescribed drug in the world. In 1992 patent-protection expired and production of the active ingredient was moved to elsewhere within the corporation. A series of new compounds were introduced into the Irish plant. The management had to compete within the corporation to secure these replacement compounds and in preparation the plant went through an extensive programme to improve competitiveness. The Cork plant is now a strategic manufacturing plant within the company, a position confirmed by the substantial expansion in capacity undertaken in 1998. Strategic plants are used for the introduction of new drugs. This requires competence in technology transfer as the plant must work closely with the corporate R&D function to establish safe and efficient processes for the bulk manufacture of new chemical entities.

WATER BATNEEC	AIR BATNEEC	GW	TIME
✔	✔	✔	7

CT	WET	SPECIALISATION	% of FIRM'S PROJECTS
78%	12%	CT • PROD • CR [97]	40%

SYSTEMS	MEASURES	STRATEGIC DEVELOPMENT
3	2	3

Table 20: Capability Indicators for Pharma K

Organisational Capability for Proactive Compliance

Pharma K has a distinctive environmental management approach which grew out of particular events in the plant's history that shaped the development of an organisational capability for proactive environmental control. The plant has achieved a reputation for good compliance with both the EPA and the local community. This

[97] Cleaner technology projects in production, involving chemical route changes.

reputational asset has been built by processes in a number of areas. A high importance has been placed on the development of effective routines for compliance. The plant judges compliance not just against the emissions limits set in the licence, but against the higher bar of the satisfaction of the community and the Agency; this has lead to the development of a conception of compliance that sees elimination and reduction as preferred options over abatement. The second, related, set of processes is for community relations. This began with putting in place routines for communication and resolution of complaints. These routines now encompass increased openness and accountability, which resulted in the decision to involve local NGOs in the licensing application process.

> Certainly long ago, with our neighbours the relationships were poor ... And we took then, again, the decision that if the neighbour complained, even if you were going to get a kick in the shins, go out to him, first of all, and then secondly if we have had a problem to say 'We have had a problem.'[98]

Prior to 1992 the production chemistry involved methyl mercaptans, a compound that is highly odorous even at very low concentrations. Problems with the containment of methyl mercaptans led to a deterioration of relations with the local community. This was exacerbated by the fact that another plant in Ringaskiddy was using methyl mercaptans and had similar containment problems. In the early 1990s both plants were prosecuted for a breach of the Air Pollution Act (1987). Pharma K chose not to take advantage of the legal loophole used by the other manufacturer to avoid prosecution and was fined the maximum amount possible under the legislation. The company has made efforts to rebuild their relationship with the local community and to restore their credibility with the regulators.

> I suppose we were fairly conscious also of the fact that in the past we did cause odour nuisance and we were regarded as being dirty, as being a plant which constantly caused offence to neighbours ... That probably also conditioned people here to say let's really go for it and try and make amends. First by getting rid of whatever problems we were causing the neighbours and secondly then by being upfront with people.

[98] All quotes in this case study, unless otherwise attributed, are from an interview with the Pharma P environmental manager, 19.8.1998.

> It was overcoming a big barrier, from being a poor company, in the early eighties and mid seventies, being regarded as a kind of pariah among companies, to trying to come to terms with the fact that we had a problem, and secondly then to tackle it head on.

In 1994 Pharma K were seeking planning permission for a large plant expansion, and both the firm and the Agency wanted the expansion to be seen to be licensed under the new IPC licensing system. In order to achieve this, the licence application was expedited, and Pharma K was the first company in Ireland to receive an IPC licence. The company undertook a programme of consultation with the external organisations that would be interested in commenting on or objecting to the proposed licence; these organisations included Cork County Council, Cork Chamber of Commerce and the local residents' association. Most significantly the company also entered into detailed consultation with its most vocal critic, Cork Environmental Alliance (CEA).

> One of the things that this company did, that wasn't repeated in any other company, maybe apart from [another pharmaceutical company] in the early days, is that we decided to sit down with Cork Environmental Alliance and try and work with them rather then using megaphone diplomacy ... Obviously, we found it was better to be *trying* to work with them than to be fighting them and having huge long appeals, the usual trench warfare that exists sometime between NGOs and companies. And we tried to, even against opposition from some of the other pharmachem companies, be a bit more open and a bit more above board.
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> We were very conscious of that, with people like CEA, certainly on our reputation many years ago, increasing the scope of our operations would have been bad news and people would have objected. We sat down with them, gave then our licence application, gave them our EIS [environmental impact statement], said what we wanted to do, discussed, in as much as we could, things like incineration and waste and so on. And when it came to our licence application, which was the first in the country, the decision was taken somewhere within CEA and Greenpeace not to object. And we did get the licence in time.

The immediate advantage to the company was that there were no third party objections to the licence and the company's IPC licence was granted without any delay. The company sees a long term benefit in maintaining the relationship with NGOs: 'hopefully, as we develop over the years, whether we change or increase what we are doing, they will have an understanding that we are doing it in conjunction with minimising risks.'

The environmental manager's philosophy of environmental management is characterised by issues of control. He explicitly links the motivation for control to the past problems with regulators and the local community, which were considered to be due to a failure to achieve control.

> We have, number 2 there [mission statement on wall], 'a commitment to operate at all times within the terms of the integrated pollution control licence issued by the Irish EPA', that is one of the prime objectives on the site. People are very sensitive about it. Did you ever see the EPA annual report? Everyone appears in it, anyone who has had a naughty letter, or has complaints appears in it. So there is peer pressure too you know. If some guy is getting regular black marks everybody knows about it. And you are at a meeting with somebody, and you are kind of looking at the table [mimes embarrassment], and thinking he must be having a hard time.
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> We feel that to try and stay in command you say to yourself 'how am I going to make sure that when I take a sample this month, next month and the month after I am not going to suddenly get a surprise and find that the whole thing has fallen down? ... Just to make absolutely sure I would like to have that on a monitor somewhere, so I can see it and look at the variation'.

In some companies, as will be seen in the case of Pharma G, control is equated solely with control of emissions and provision of adequate treatment is seen as being sufficient for control. In Pharma K, the pursuit of control is more proactive as environmental concerns are addressed through the consideration of the whole production system. Within this approach the introduction of pollution prevention is seen as an effective way of improving environmental control.

> You begin to think almost as if you are a molecule yourself. Where do I go next? What happens when I leave the reactor? Is it going to go out to atmosphere? Is it going to be destroyed in the incinerator? Is it going to be absorbed in a scrubber? What is going to happen to it? What happens to the stuff in the scrubber? What are you going to do with that? How do I contain it? ... You are thinking much more from a to z.
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> So the thinking - really trying to close the loop, have a closed system. If you cannot reduce it, it is inevitable that you are going to have waste. A

> while ago we had a solvent which is frowned upon and we made a lot of noise about it here … We brought it to the attention of corporate environmental and we have a good chance they will use something a lot more benign … It would be very easy just to accept that [use of a listed solvent] and live with it. What the environmental agency would say to you is 'if you are going to use x instead of y, and substance x is a nasty, look on it this way, you are going to have to account for every kilo of it'. So in a sense there is a kind of a burr under the seat of your pants, it is easier to get rid of it. You can do it, we have the plant design to keep it from getting out into the atmosphere, but you are worried about it all the time, whereas with a more benign solvent not so much. The pressure is not as much. That is prevention at source.

The idea that the regulators function as an irritant to encourage compliance and improvement is also the environmental manager's view of his own function within the plant.

> An awful lot really you have to do yourself and try and change the way people think, generally it does, after a while when you're banging away about it and talking to people about it, and giving them a formal briefing on it maybe every so often. And they ring you up if something is wrong. It is a gradual thing. It is a bit like dealing with the neighbours: after a while people begin to say 'oh you must be serious about that all right because you went about it or you are coming out the top to us about it'. You have to establish that.
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> Waste storage here on site is something that has improved here over the last year or two, because we hammered away at it … And now we are going into a mode where, a preventive sort of a thing, if people are sending drums out of the process which have wastes in them they have to complete paperwork and it will be computer based, we will have an inventory of waste. We will be able to look at a drum that has been issued three months ago and say why is that here three months later. And the people gradually begin to say 'every time I put a drum out there is going to be a question about it'. It is a bit command and control, but it gets results in the earlier stages, when you are annoyed with ways things are going, or you are not happy about something. Maybe in the years to come we won't have to be going around kicking people up the backside about storage.

The plant has built trust and credibility with the EPA, responsible for its formal IPC licence, but also with the local community, whose cooperation can be seen as a 'licence to operate.' This organisational capability for proactive control has built credibility and afforded the plant some strategic leeway in terms of its operations, as seen in the licensing process and the approval for the plant expansion.

Organisational Capability for Solvent Recycling

The company has recently begun solvent recycling at the plant. This is a new area of expertise for the plant, as solvent based chemistry was only introduced to the plant in 1992. At that point the plant did not have much experience dealing with solvents, though they did have some recycling experience.

> The big enemy here in the earlier days was the odorous compounds, methyl mercaptans, and all our technology revolved around that, and we were inclined to regard solvents as tame ... I could see that at first we were almost incredulous that you had to contain a solvent, 'sure nobody can smell it.' Very quickly you learn of course.

The plant has developed an organisational capability in solvent recycling. This capability is built on a cluster of routines and resources, integrated across functional groups, that allows for the development and performance of solvent recycling in a smooth and efficient manner. The specific solution was developed by using the relationship with the corporate environmental research laboratory (ERL); this close and productive relationship had been developed by routines for building cooperation, shared understanding and learning.

For Pharma K solvent recycling represents a solution to a regulatory compliance problem. The development of the capability evolved out of the dynamic processes for problem identification and solving, especially routines for data generation and evaluation, shaped by the plant's strategic vision (or Penrosian 'image') of the importance and nature of proactive control. In 1989 anticipation of new regulations led to the identification of the need to upgrade the wastewater treatment plant.[99] A task force was established to evaluate waste streams and processes and develop technical options. The project ran for four years and culminated in a £4m upgrade to the wastewater treatment plant. The company responded to the introduction of solvent-based products by establishing another task force in 1992, the Waste

[99] Some of the information on this project is taken from Clayton et al. (1999).

Minimisation Working Group, to continue the earlier work on waste stream evaluation, but applied specifically to the new solvent waste streams. External advice (from the Clean Technology Centre at Cork Institute of Technology) was engaged to provide solvent mass balance analyses to develop a profile of solvent use and account for losses. The project lead to increased understanding of the parameters of production and waste at the plant. The group identified that as the volume of solvent–based production increased the company would exceed the capacity of its existing incinerator by 1996 and a decision had to be made about whether to invest in increased incineration capacity. The work of the Working Group project lead the environmental manager to suggest that they should look at increasing solvent recycling.

The plant used help from the ERL to develop computer simulation models of solvent recovery. The next step was to demonstrate at a lab-bench scale that recycling and reuse was feasible. Solvent reuse has implications for FDA approval, and the corporate Transnational Regulatory Affairs group began the process of filing for approval of the change to the process.

> We were looking at big amounts of solvents and no central body of people here who could do a lot of work because we do not have the hands to do it. I remember saying to someone 'look, I'll start roping in ERL and see if they can do anything on it' and they were only too pleased to do it.

In 1991 a new corporate environmental policy was launched which included defined environmental responsibilities. R&D has responsibility to include waste minimisation objectives in the development stage of drug development. Plants have responsibility for waste minimisation in the final process route and as ongoing continuous improvement. These objectives were given increased focus from 1996 when the ERL became part of the R&D function. The ERL has been an important resource for the Cork plant, the relationship has become 'less remote' and, while the help was given on an ad-hoc basis initially, is now routinised with a video conference meeting every two months and an annual two day visit.

At the end of 1994 a chemical engineer then ran a pilot project for six weeks on some unused plant, successfully demonstrating closed-loop solvent use. Solvent recycling required an £11.4m investment. Financially the solvent recycling solution showed a higher rate of return than any of the alternatives (incineration on-site; incineration off-site by a third party; recycling off-site by a third party). The recycling project had estimated savings in the first year of £4m (£2m in saved materials, £2m in saved costs of incineration). Non-financial factors were also very significant. Incineration is an emotive issue, and the introduction and licensing of new incineration facilities in other Irish pharmaceutical companies had developed into flashpoints for high profile action by pressure groups and local communities. Recycling on-site allowed Pharma K to maintain ownership of its waste, which was seen as important given trends in EU legislation to discourage third-party disposal.

The project was approved in June 1996. The recycling plant is multipurpose in that it can be configured for recycling of solvents with different properties. As knowledge and experience of the system increases the range of processes and solvents that can benefit from in-process recycling has been widened. The Cork plant now has the capability to do some of the development work, such as the development of computer simulation models, that was previously carried out in the ERL.

Solvent recycling has increased the flexibility of the plant, particularly in relation to the introduction of new products. This supports the plant's status as strategic manufacturing plant within the corporation. The closer relationships with corporate functions are welcomed as an important part of maintaining control in the light of increased pressure on technology transfer times for new products. 'Things are happening fast nowadays, they go from the bench almost into the plant.' As a result of the closer links between R&D and manufacturing, the environmental manager reviews proposed new compounds up to 18 months before they are introduced for manufacturing. This allows for the identification of waste streams and consultation with ERL. An example of this is a new product which went into production in 1999. This process used a very high amount of a listed solvent, toluene, and would have created severe problems for Pharma K with respect to compliance with the limits set in the IPC licence. ERL began lab work on potential toluene recycling in 1997 and came over to assist with a pilot run and transfer of the process to Cork in May 1998; the plant completed pilot recycling well in advance of the compound being introduced into the plant.

The strategic alternatives open to the firm at the time of the project when it was facing the prospect of installing an expensive and politically troublesome incinerator and now, as the plant continues to expand the quantity and type of solvents it uses, were broadened because the firm was able to call upon processes for problem-solving and processes for accessing external expertise, allowing the plant to build a capability for solvent recycling.

Organisational Capability for Reduction at Source

In projects reported to the EPA as part of the environmental management programme, Pharma K has a strong record of pollution prevention through process development, with approximately 40 percent of the environmental projects reported being process development projects. There have been two significant phases of source reduction at Pharma K. The plant produced high volumes of one product from 1975 to 1990; this allowed for a series of modifications to improve product yield, and also reduce waste. With the change to a series of new solvent-based compounds in 1992 there was a pause in process development work of this kind, and improvement projects did not start again until 1994. However, the use of chemical route changes to achieve reductions in waste does not appear to be environmentally driven, or even significantly integrated with the environmental management function. It is rather the case that work is driven by the commercial considerations of better yields, and the associated environmental benefits are considered as a welcome bonus. 'It is not always because of waste reduction, it might be because of trying to get a bigger batch. More than likely it will go in the same direction as waste reduction.' It appears that the environmental management function have the most influence on the impact of the chemical route through pre-introduction intervention through the relationship with

ERL as described above. The plant does not have extensive processes for the use of teams or the routine involvement of Manufacturing or Process Development in the pursuit of cleaner technology projects. Process development is historically a much stronger function at Pharma K than at either Pharma P or Pharma C. Both of these plants have pursued strategies of mutually reinforcing learning in process development and waste minimisation, leveraging expertise acquired from working with the CTC. In Pharma K the process development function has not taken on projects outside its established domain.

Conclusion

Historical pollution problems mean that Pharma K sees environmental management as a strategic function, essential to securing the plant's licence to operate from regulators and the community. This supports the plant's role as a strategic manufacturing site by maintaining flexibility of action. In addition to a changed approach to external relations, the other significant change in environmental management in this plant has been an improved relationship with the corporate environmental function, built on expertise acquired within the environmental function through past projects and work with external advisors such as the CTC. However, the environmental manager's view of his role as being vigilant in ensuring compliance, and serving to remind others of the importance of good control, may explain why the plant is not as developed as others in its view of continuous improvement through process development.

> So trying to have a continuous improvement in the sense of waste reduction, I think the sort of continuous improvement that we do is we have formal audits now on site where we do a major audit six times a year. It is a very formal thing with a written documentation of it, meetings with people after it saying 'we do not want this happening anymore' if something is poorly done.

The goal of control has shaped the development of environmental management at Pharma K, but may also operate as a constraining factor in terms of the opportunities for cleaner technology not actively pursued.

Case Study – Pharma G

Introduction

Pharma G is a subsidiary of one of the world's largest[100] pharmaceutical corporations. It has been operating in Ireland since 1975 and employs almost 400 staff. The Irish plant has 'lead status' within the corporation, meaning that it is used for the transfer of new compounds to the manufacturing process; a significant process development function supports this work. The corporation decided to make a large investment in expanding the Irish plant in 1996. Capacity will be expanded by 50 percent and a launch platform facility will be developed for the production of small clinical trial batches of new compounds. The decision to make the investment in the Irish plant, rather than any other plant, is a reflection of its position as a centre of excellence within the corporation. The investment was made on the basis of the plant's cost-competitiveness and also its competence in technology transfer, considered by the management to be located in the reliability, know-how and quality of the staff (Pharma G IPC application, EPA files, 1994).

WATER BATNEEC	AIR BATNEEC	GW	TIME
X	✔	X	141

CT	WET	SPECIALISATION	% of FIRM'S PROJECTS
77%	19%	no specialisation	-

SYSTEMS	MEASURES	STRATEGIC DEVELOPMENT
1	1	0

Table 21: Capability Indicators for Pharma G

[100] Fortune Global 500 companies, 1999.

Evolution of Organisational Capabilities

Applying the evolutionary theory of the firm model to the development of environmental management capability in Pharma G we can see that the plant has developed environmental management capabilities in a narrowly focussed area of competence, that is, engineering solutions for abatement to achieve compliance. The plant's view of environmental management has a very strong control technology focus: 'legislation only requires control'.[101] Managers in the plant, and at corporate level, talk about waste minimisation and pollution prevention meaning not source reduction but minimising release of emissions through control and equipment.

The plant's approach to environmental management is strongly consonant with the corporate view. Corporate information describes the company as 'an engineer's company': 'no other pharmaceutical company utilises the expertise of engineers more than [Pharma G Corporation]' and 'more than a third of Manufacturing's salaried employees hold engineering degrees'. In describing the work an engineer might be involved in no mention is made of cleaner technology: 'Environmental projects at [Pharma G Corporation] include: monitoring, remediation programmes, and laboratory testing; compliance programme for federal, state, and local regulations; implementation of new regulations; waste recovery system' (Pharma G corporation website). Any environmental reports produced by the company reflect the greater significance placed on abatement solutions; the 1996 environmental report mentioned cleaner technology as an aspiration, but the only concrete references to actual or planned projects concerned abatement technology. The corporation made a high-profile commitment to reduce toxic emissions by 90 percent over five years and eliminate emissions of carcinogens over three years. This was achieved by upgrading abatement technology worldwide. The 1996 annual report announced that the 90 percent reduction goal had been achieved. No new environmental goals have been announced.

[101] All quotes, unless otherwise attributed, are from an interview with the Pharma G environmental chemist, 20.10.1998. This interview was not taped and consequently this case study makes minimal use of direct quotes; quotes used were taken from the written notes of the interview.

Environmental management systems were initially developed at the plant in order to comply with corporate objectives. However, unlike the previous case plants, there is no evidence of processes whereby the corporation acts as a problem-solving resource for the plant, or is able to integrate the plant's environmental concerns back into product development. The first environmental management programme in Pharma G was established in 1990. This was in response to the corporate global policy which had the following objectives: (i) minimise release of chemicals into environment (ii) research innovative routes to find waste minimisation and resource conservation (iii) self-sufficiency in treating/disposing of wastes (iv) energy and resource conservation. The goals of the environmental management programme developed at Pharma G to implement this policy were more limited in scope: '(i) training of people to constantly maintain good environmental practice; (ii) replacement, upgrading and retrofitting of equipment; (iii) keeping abreast of technological improvements' (Pharma G IPC application, EPA files, 1994). Between 1987 and 1994 the plant undertook a substantial programme of equipment upgrading, with £11m spent on environmental equipment over this period; this programme was again driven from the corporate level, being a response to changes in corporate engineering design standards. In 1995 the company invested a further £15m, primarily in a thermal oxidiser for VOC control which has achieved the plant's compliance with the 90 percent reduction goal.

The development of environmental management at Pharma G has been strongly influenced by corporate requirements. The parent company took part in a voluntary US EPA initiative on the measurement and reporting of toxic releases (US TRI). Pharma G established a structure to provide annual site reports to meet the plant's requirement under the US TRI programme. This system is still in place, and is described by the plant as an 'integrated site management approach' (Pharma G IPC application, EPA files, 1994). The emphasis is on monitoring and control of emissions: 'the approach to waste minimisation and clean technology is based on measurement and control' (Pharma G IPC application, EPA, 1994). The components of this structure are: (i) an environmental database; (ii) weekly environmental performance reports; (iii) weekly meetings; (iv) monthly reports on sludge/solvents;

(v) detailed end of production run evaluations. Where in Pharma C the corporate reporting structure system became the foundation of a more sophisticated and integrated environmental management system, in Pharma G no such evolution has occurred and the corporate system is seen as being sufficient.

The plant does not have a very formalised EMS, something they see as an asset, describing their strength as being in people and knowledge, not paper and procedures. They measure the adequacy of the EMS in terms of compliance with the EPA requirements for an EMS and consider that 'we satisfy those minimum requirements.' The EPA has laid out 'the requirement for the additional elements which in the main are related to the housekeeping function of the EMS e.g. document control, record-keeping, corrective actions etc.' (EPA, 1997, p. 7). Acknowledging this requirement, the plant has conceded that there may be weaknesses in not having a more documented and proceduralised system. At the time of the case study visit Pharma G had engaged consultants to carry out a gap analysis, comparing the plant's EMS with the ISO14001 model, to identify where changes could be made to strengthen the EMS. However the pant did not anticipate that this would change their view that there is little value for the plant in moving to a formally accredited EMS. This suggests that the exercise had more to do with satisfying the regulator than any real internal change.

Another licence condition imposed on firms by the EPA is that employees receive environmental training. At Pharma P and Pharma C this training is carried out with the goal of increasing the capacity of employees to identify opportunities for cleaner technology use. In Pharma G the training requirement is complied with, but is viewed as being only of 'general interest' to employees, without being of actual relevance to their ability to perform. Training is limited to providing awareness of the EPA and the IPC licence and training on the operation of abatement equipment.

Abatement and Cleaner Technology

The plant identifies its main achievement, with respect to the development of environmental management at the plant, as the evolution of technology, or more precisely equipment, driven by evolution of the product mix. When asked how environmental management had changed at the plant over time, the environmental chemist described how the technology has advanced from water abatement, to thermal oxidiser (because of new immiscable solvents), to carbon adsorption (to deal with chlorinated solvents) to the new fume incinerator. The goal of the environmental management function is to support the plant's flexibility in taking on new products by ensuring that they have the capacity to abate all possible waste streams.

Analysing the projects reported to the EPA, Pharma G does carry out cleaner technology projects, and compared to the cohort of 16 firms, has only an average reliance on abatement focussed projects. However the plant has a very high use of equipment-based projects, being the third highest user (in both percentage and absolute terms) out of the 16 firms analysed, with over half the projects reported to the EPA being equipment-based.

The major cleaner technology initiative at the plant is solvent recycling. 'An important aspect of chemical processing operations both from an environmental and financial impact, is to maximise the volumes of waste solvents that are recycled, recovered and reused' (Pharma G EMP, EPA files, 1997). This has received particular emphasis in the 1990s, with a 45 percent increase in the quantity of solvents recycled achieved between 1994 and 1997. The increase was achieved through investment in recovery equipment and driven by the changed mix of production at the plant. The plant has pursued a programme of investment to increase its flexibility in handling different types and mixes of solvents. Another initiative that has been undertaken is a review of cleaning procedures. This has identified a solvent change allowing for increased recovery. Equipment changes have reduced the total of cleaning liquid (water and solvent) by 75 percent.

Source Reduction and Process Development

The plant itself does not have a routinised approach to source reduction. A number of reasons were given for this: the difficulty of getting chemical route changes approved by the US FDA; a right first time philosophy ensures that production processes have been optimised in respect of environmental impact prior to being introduced at the plant; the products produced at the plant are well established and therefore all opportunities for source reduction have been exhausted. The view is that the plant has 'gone as far as we can go with elimination and modification.'

The plant has not established any waste minimisation working group or programme. In 1994 there was an interdisciplinary project to 'review and document all the waste streams generated' (Pharma G IPC application, EPA files, 1994), but this was focussed on the recovery, handling and shipping of waste. The plant uses small quantities of chloroform (approximately 3 tonnes p.a.) which is a List 1 solvent, indicating that it is highly toxic. It is a condition of the plant's IPC licence that they put in place 'a programme to identify methods by which a reduction in the emissions of List I and List II substances, and all priority black list substances, from the activity may be achieved' (Pharma G IPC licence, EPA files, 1994). Pharma G's approach to the management of chloroform is to focus on measuring, reporting and minimising losses; they do have any plans to explore source reduction. This can be seen in direct contrast to Pharma C and Pharma K, where strenuous efforts were made, driven by the environmental management function and involving corporate R&D, to have List I substances removed from production.

It is unclear how proactive the plant is in making use of either its own process development capability or its relationship with corporate R&D to pursue process changes to achieve pollution prevention. In the AER reference is made to process modification projects, such as a laboratory investigation programme on one new drug that is hoped to lead to recovery of four solvents from the process. The assistant environmental chemist described the relationship with corporate Environmental Services as being limited to the provision of information on waste composition to assist in determining the opportunities for recovery. In 1996 one modified process, with increased solvent recovery, had been piloted in the plant, but at the time of the case study visit in 1998, no new processes had been piloted subsequently. The EMP for 1998 gives details of six on-going process investigations, at different stages of completion, one of which will be implemented in the main process facility in 1998.

Other projects outlined for 1998 include seventeen equipment based projects, mostly relating to abatement systems, as well as operations changes in materials handling. Engineering solutions are generally simple, often being drop-in, off-the-shelf equipment changes. Other kinds of changes, projects involving changes to information, processes or operations, are usually characterised by the development of deep understanding, often require co-operation and integration between functions, and with uncertain or less definable outcomes (Christie, 1995). Projects involving these more complex processes of understanding and discovery are carried out by Pharma G, and 40 percent of the projects reported to the EPA are of this type. The plant has implemented projects for improvements to cleaning processes, for yield improvements and chemical route changes. It seems however that beyond recording these projects in reports to the EPA, these projects were not in any way environmentally driven, and that the environmental management function at the plant neither instigated them nor was involved in their development or implementation. These projects were undertaken for financial and efficiency reasons, and the positive environmental side-effects were recognised and reported. There is no evidence of processes whereby environmental management is integrated with other functions, either to influence the integration of environmental goals into those functions or to develop joint understanding and solutions to environmental problems. The role of environmental management is clearly to ensure control and compliance; its contribution to the plant's strategic development is to ensure that the plant is never constrained by being unable to achieve the necessary standards of abatement. Pharma K has a similar situation, with a strong process development function that maintains a high degree of autonomy. However, in Pharma K the environmental management function has strong links with other functions, inside the plant and within the corporate structure. It also has a much more proactive conception of its role and remit.

Regulation Experience

Although the plant's environmental management focus is on abatement for compliance, Pharma G has a problematic relationship with regulators and the community. There have been persistent complaints of damage from air emissions made against the company by a neighbouring farmer. A high-profile legal case ended in a substantial award being made against the company in 1987. The case showed that the company had not been running their incinerator to its operating specifications, resulting in incomplete combustion of the toxic materials, and in breach of their planning conditions (the case predated the introduction of air emissions licensing). The award was on the basis of 'nuisance damage', meaning the company was not found to be strictly liable for pollution but the Supreme Court judgement was that 'it was proven as a matter of probability that [the plaintiff] suffered ill-health as a result of toxic emissions from the factory' (quoted in Allen and Jones, 1990, p.43).

The IPC licensing process did not run smoothly and was subject to delays. After the initial IPC application was submitted the EPA requested clarification on 13 substantial points. They queried the information supplied with respect to the new thermal oxidiser (commissioned in 1989), and suggested that the company needed to review the BATNEEC guidelines, as 'the oxidiser design and operation should be examined in the light of this note' (Pharma G correspondence, EPA files, 1994). When the full information was supplied, after a delay of three and a half months, the EPA raised concerns that the thermal oxidiser was not being operated correctly: 'The Agency considers that the ducting of vapours from processes with chlorinated solvents to the thermal oxidiser is unacceptable... In light of the above, provision for the abatement and emissions of vapours from processes with chlorinated solvents is required' (Pharma G correspondence, EPA files, 1994). Pharma G subsequently provided details of additional abatement for chlorinated solvent vapours. The company objected to the proposed conditions of its licence in five cases relating to monitoring requirements and licence parameters, citing the NEEC ('not entailing excessive cost') element of the BATNEEC standard and arguing that the high costs and negligible impact of changes would compromise the plant's competitiveness without improving environmental protection.

An Taisce, one of the bodies included in the EPA's licensing consultation process, did not raise any formal objections to the plant's licence, but did submit concerns with respect to the liquid waste incinerator, 'given the history of maloperation of this incinerator by the same management' (Pharma G correspondence, EPA files, 1994). The licence requires that the incinerator be decommissioned by 1999 and lays down stringent provisions for its operation in the interim period. The plant was required to obtain specific authorisation from the EPA each time it wished to operate the incinerator. The first of these requests was denied, as the EPA considered that the plant had failed to provide a report on the incinerator and the decomposition of materials. Approval was granted following provision of the information, but the EPA attended the procedure. Approval was granted for three subsequent uses of the incinerator in 1995 and it has not been used since 1995. Complaints have continued to be made about toxic air emissions (eight complaints in 1997), and in December 1997 formed the basis for an unannounced audit by the EPA. The EPA requested full manufacturing records about the running of processes 'involving the evolution of gases' on particular dates related to complaints made about 'burning' air emissions. The audit concluded that the EPA was 'not worried' about the operation of these processes, that the EMS for the maintenance of documentation was 'well developed and operating well' and the company was commended for this (Pharma G audit report, EPA files, 1998). Problems of this kind are costly and time-consuming, and throw into relief the tangible advantages gained by Pharma K in taking a similarly difficult community relations situation and working to create co-operation and understanding.

Conclusion

From the documentation presented to the EPA and the case study visit, it was not possible to find evidence of established, smooth-running routines that would support cleaner technology development. By the plant's own admission they have not developed formal environmental management systems. The environmental management function does not have routinised links with other functions within the plant, or with environmental and R&D functions within the corporation. Nor is there any evidence of routines for deepening understanding, such as information gathering, problem identification and solution development. The environmental management function's perception of its role, a perception held also at corporate level, is to support the plant's performance and development by ensuring compliance with regulations through flexible abatement technology.

Case Study – Pharma L

Introduction

Pharma L is a subsidiary of a US pharmaceutical multinational and employs 300 people in the organic synthesis of 100 products and intermediates. Pharma L began production in Ireland in 1980, when they bought a pre-existing pharmaceutical manufacturing plant from an Irish company. The physical plant dates from the 1960s. The Irish plant was until recently the only bulk organic synthesis facility within the corporation. Its historical position as sole manufacturing facility means that the plant has a very developed pilot plant and process development function, working on the transfer of technology from R&D laboratory to plant, including the development of alternative synthetic routes. Also, the need to be able to produce 100 intermediates and products in a facility with five production plants has meant that flexibility is an important requirement for the plant. The plant is a 'multi-stage, multi-step synthesis plant with the maximum flexibility applied to where each product-step can be manufactured' (Pharma L IPC application, EPA files, 1994). The company warns that where the need to maintain flexibility is in conflict with the environmental objectives of the Agency it may not be in a position to compromise: 'The flexibility is the corner-stone of the company's policy and approach and a major reason for the development and ability to maintain its position in the market place' (Pharma L IPC application, EPA files, 1994).

WATER BATNEEC	AIR BATNEEC	GW	TIME
X	X	X	53

CT	WET	SPECIALISATION	% of FIRM'S PROJECTS
70%	24%	CT • PROD • CR [102]	33%

SYSTEMS	MEASURES	STRATEGIC DEVELOPMENT
2	1	1

Table 22: Capability Indicators for Pharma L

[102] Cleaner technology projects in production, involving chemical route changes.

Evolution of Organisational Capabilities

Pharma L has had limited success in developing integrated environmental management capabilities to meet the requirements of the new IPC regulatory regime. The lack of organisational capabilities for environmental management is a reflection of the low priority given historically to this function, and also, as seen in Pharma G, to a mindset that equates environmental management with compliance. The position of environmental officer was created to manage the IPC licence application and to ensure licence compliance. 'It was always end-of-pipe, meet your limits, everybody is happy. Things have changed, and whether old dogs can learn new tricks or not ... '[103] No routines have evolved to either diffuse environmental responsibility into other functions, or to give the environmental officer the opportunity to involve other functions in environmental management. Pollution prevention responsibilities remain the sole preserve of R&D and the environmental manager has no formal, and little informal, influence on the direction of pollution prevention projects.

Regulation Experience

Pharma L has experienced significant difficulties in attaining the water and air emissions standards set in its IPC licence. At the time of licensing the plant was in the process of achieving compliance with the 1987 Air Pollution Act, and a goal of compliance by June 1997 had been agreed with the local authority responsible for licensing.

The first problem is that the regulations had been misinterpreted[104] and it had been assumed that the air emissions standards, as laid down in the regulations, applied to *each vent*, when they actually applied to total emissions from the *whole site*. As Pharma L has five main vents, they were potentially working to an emissions standard that was 500 percent higher than the actual standard. Plants 1 to 4 were older technology and would require extensive retro-fitting to be able to meet the limits for organic solvent waste streams. Plant 5 was built to comply to the new standards, but

[103] All quotes in this case study, unless otherwise attributed, are from an interview with the Pharma L environmental officer, 5.9.1998.

[104] It is not clear whether responsibility for the misinterpretation lies with the local authority or the plant.

at 100 percent of the emission limit value, and not the 20 percent or less that was actually required (Pharma L IPC application, EPA files, 1994).

In the IPC application there were problems with provision of full information on the character and volume of the plant's air emissions because air monitoring procedures were not in place at the plant: 'at present [Pharma L] has not accumulated a detailed database of actual air monitoring samples' (Pharma L IPC application, EPA files, 1994). The plant provided 'theoretical' or 'worst-case' estimates in lieu of data. The plant requested leniency from EPA in terms of allowing three to four years for a programme to meet BATNEEC standards for air emissions and in respect of interim monitoring requirements.

Prior to the introduction of IPC licensing the plant had been involved in a programme of improvements to its water waste streams and wastewater treatment plant. The plant discharges into a river, and places a high importance on minimising the impact of its effluent. However, despite a major capital investment in the wastewater treatment plant to meet BATNEEC, and a significant programme of pollution prevention through process changes, at the time of licensing Pharma L was not in a position to meet the new BATNEEC standards for emissions of nitrogen (limit set at 15mg/litre whereas actual recorded by Pharma L was 10-100 mg/litre) and organohalogens (limit set at 0.1mg/litre whereas the actual emissions recorded by Pharma L were 11 mg/litre).

Pharma L made a formal objection to the proposed terms of its IPC licence. Management at the plant argued that it would have to severely curtail operations if not allowed exceptions in respect of: (i) removal of a condition to achieve reductions in the use of nitrogen and associated emissions of ammonia; (ii) provision of more time for compliance with air BATNEEC; (iii) exemption of the pilot plant from air emission limits, as this would otherwise curtail experimental work on processes; (iv) more generous MDC emission limits (0.5 kg/hour to 3.8kg/hour). The EPA allowed the requested changes. The licence was issued with two sets of emission limit values

(ELVs), the second, more stringent set (about 30 percent of pre-compliance limits) applying from the date agreed for BATNEEC air compliance of June 1998. Monitoring requirements for the pre-compliance period were less demanding, being quarterly rather than continuous. COD limits, for water effluent, were increased by 300 percent from the original limits proposed; the pilot plant was allowed exemption; and the limits on emissions of MDC were relaxed.

After the granting of the IPC, the plant began evaluating air abatement technology options, before finally deciding to install a thermal oxidiser, at a cost of £15m, planned to be operational by May 1999. The period between the granting of the licence, in 1994, and the commissioning of the thermal oxidiser has seen problems with breaches of air and water emission limits. In June 1996 the EPA wrote requesting an explanation and corrective actions in respect of six incidents of emissions exceedences since Jan 1996. In May 1997 the plant was reprimanded for the release of unapproved substance and for allowing the limit on chlorinated solvent emissions to be exceeded. There have also been problems with chlorinated solvent emissions from the WWTP; in June 1997 EPA wrote to require that the company 'ensure a more rapid operational response is taken on-site in the event of any additional exceedences occurring' (Pharma L correspondence, EPA files, 1997). The thermal oxidiser represents a significant investment by Pharma L. It was a not a requirement of the licence, but it was ultimately decided by the company that, despite the high cost, this was the most secure and least disruptive way to achieve compliance.

> It was really good will I suppose on our part that they asked us to reach a certain level and we said we could do that. Well I suppose to some extent we could and we couldn't. It was almost a situation where what they had asked us to do, you could do, but it was easier to do it another way, from an engineering point of view. It was more expensive but it was easier, more convenient, I mean there was a whole operations side to have to consider as well the monitoring.

The environmental officer's view of the plant's environmental management approach centres around managing the relationship with the EPA, ensuring compliance in emissions and in reporting requirements, rather than driving forward any programme of change.

> I came on board around the time the EPA were coming in, so I would say I was here six to eight months when the application had to go in. I came just before that. I think it was recognised at the time that what the EPA were looking for, not only in the application but in the operation of it, day-to-day running of the licence and what we were doing before, was a massive jump forward. Not so much more from an activity point of view, in terms of hands on out there, but actually just the paperwork. I think the whole paperwork exercise is up to 70 or 80 percent of what I do. There is a huge leap forward from that point of view.
>
> That is one of the main direct effects we have seen is just that there has been a huge jump in the amount of paperwork...I think when they [EPA] came along we had the programme in, we had our waste minimisation committees long before that, but now it was a matter of recording it a bit better from an environmental point of view.

The environmental management function's responsibilities are discrete and relate to issues of systems and reporting and ensuring compliance through abatement.

> There was a lot of work that was being done that was not necessarily for environmental reasons, it was financial or personnel, safety or whatever. So it was just a matter of maybe formalising that better and recording it better, so you can trend your successes in reports to the agency.
>
> At the end of the day it all comes down to money I think, who has got money and who is willing to spend it.
> *But also experience? [question from interviewer]*
> Experience to some extent, you are right in that we have been putting the systems in gradually over time. ... But having said that even if we had nothing here and the EPA came in we would have just spent the money and got it in quickly, There is no problem doing that, because we can afford to do it. ... At the end of the day it is whoever has the most money feels the impact lesser.

The move to a cleaner technology emphasis has been a change for the plant, 'previously [the local authority approach] would have been "end-of-pipe, here is your limit, we don't care what you do inside."' The adjustment has been difficult for the plant.

> I think we have always had an environmental management system, and environmental considerations were always a part of every project, although traditionally it has always been end-of-pipe, meet your limits. I

> think it is slowly changing ... We are now starting to look at these things and so on. I have not seen a huge definitive change approach in people's mentality. But it is slowly. It is hard to quantify ... I think a lot of what has been done is still seen as compliance.

Environmental improvement is characterised by the company as a function of equipment and investment, rather than the use of experience or capability.

> At the end of the day it is whoever has the most money feels the impact lesser. The bigger companies were always better anyway because they had the money and so are going to spend more money on the controls, whereas the smaller companies might not.

The plant does not make use of routinised continuous improvement teams. In contrast to practice at Pharma P, Pharma C and Pharma K, the environmental officer has not been involved in projects that involved other departments in addressing environmental concerns. Pharma L has not reported projects involving manufacturing, (such as the process and operations improvements seen in the other cases) and the environmental officer did not see much opportunity.

> I think the problem a lot of the time is that ... the operators are being hammered by production and by quality... They are very aware that here you have a set of instructions from your batch sheet on how you should make this product, and you cannot deviate one way or the other, so that they are very focussed on that. They might say this is slightly wasteful, but they are not going to say it because that is what the batch sheet says.

In 1995 there was an attempt at the plant to involve production staff in an environmental employee suggestion scheme whereby all employees were circulated with a request for environmental improvements. The scheme did not generate any significant projects: 'I could accept that maybe people do not understand what waste minimisation is, or what it is all about. Maybe that is something we need to work on improving.'

In addition to an absence of routines spanning and integrating groups within the plant, there is little evidence of routines linking the environmental function with valuable resources and knowledge outside the plant. There is a corporate technical resource available to assist with problem solving in plants. Pharma L do not make use of this resource, because of the high technical expertise on site, nor do they feed their problem-solving experience back into corporate resources, beyond copying them on reports. 'The information goes up well but it doesn't come back down.'

Nor does the plant make significant use of external consultants. They have retained technical consultants for engineering projects such as the evaluation of alternative air abatement technologies and the design of the thermal oxidiser. They have used the services of the CTC to assist in generating a environmental improvement programme, but ultimately chose not to use the advice.

> We have a very good technical staff here on site. We are not like a bunch of managers that do not know anything about waste minimisation. There is a lot of people here that are technically good backup staff and we can do this work here ourself. So we do not think CTC can offer us anything fresh at this point in time.

The plant's ability to develop an environmental management system capable of driving continuous improvement and the adoption of cleaner technology is further constrained by the separation of environmental management responsibilities from pollution prevention responsibilities. The operations manager has responsibility for compliance, monitoring, waste management and waste minimisation. The director of R&D has responsibility for the reduction of waste production and the environmental review of new products. The operations manager's responsibilities are largely delegated to the environmental officer, a position created during the IPC application period. The environmental officer is specifically responsible for development of procedures; training; documentation; and policy. There are no formal routines linking the waste reduction work done by R&D and the rest of the environmental management function, beyond 'good communications exist between these persons ... certain issues require consultation roles' (Pharma L IPC application, EPA files, 1994).

Cleaner Technology

Pharma L's R&D function has the goal of 'safe, environmentally–acceptable processes that deliver high-quality product at minimum cost' (Pharma L IPC application, EPA files, 1994). Many of the environmental performance improvements achieved by the company have been driven by R&D, and the company considers that 'there is a considerable match between the goals of process development and those of an IPC directed policy' (Pharma L IPC application, EPA files, 1994).

In addition to pursuing cost-minimising process development that has environmental benefits, the R&D function has acted as an important environmental problem solving resource for the plant. In 1991 difficulties with the management of the plant's wastewater treatment lead to the establishment of a waste minimisation committee. There were problems with consistency in the operation of the WWTP; with high ammonia emissions; with high use and cost of acetone; and the plant anticipated the need to reduce use of chlorinated hydrocarbon solvents because of regulatory trends. The investigation of the problem and the development of the solutions were led by R&D. Ammonia emissions were reduced radically through the development of new synthetic chemistry: a 75 percent reduction in liquid ammonia emissions was achieved through removal from two processes; aqueous ammonia was reduced by 90 percent through removal from four processes. Another radical change in process chemistry reduced the use of MDC (a chlorinated hydrocarbon solvent) by 71 percent. An engineering solution for the reuse of acetone for cleaning reduced use by 76 percent. Development, approval and implementation of these changes took several years, and the overall result was a reduction in COD[105] of effluent of 70 percent.

R&D continues to explore waste minimisation projects. These projects are identified within R&D by the process chemists and approximately 10-20 percent of their work involves considering the environmental waste implications of products. Progress is reported to the Waste Minimisation Committee, which meets quarterly. Projects are driven by a combination of environmental and economic drivers, 'the economics, I

[105] COD, or chemical oxygen demand, is one measure of the cleanliness of wastewater.

have to admit, would be the main driving force. Can we make this cheaper?'[106] Current successes being implemented include the company's leading product, an anti-histamine drug accounting for a large proportion of production. The original process had a high environmental impact and difficult waste management implications, and several phases of process improvements have been explored. Another synthetic route was reworked to eliminate 30 tonnes of organic waste per annum. Unlike other pharmaceutical companies included in this study, Pharma L does not feel constrained from pursuing improved synthetic chemistry by the problems of re-registration with the FDA, although they do point out that the delays associated with re-registration make process improvement a very long-term environmental strategy.

The environmental work done by R&D is all focussed on water effluent improvements, which despite the earlier programme are still problematic in some areas. 'We still want to concentrate on the water waste. That to us is the most difficult to treat problem. We have to keep water quality high.'[107] The work does not have the same focus that it did in the early 1990s, and there is a belief that 'we are approaching the tail end of the success curve'. In particular, although there are still problems with ammonia in the WWTP, it is felt that opportunities for process development have been exhausted.

Furthermore, any projects related to the reduction of air emissions, such as an exploration of butane substitution, are no longer being actively considered, as the high level of air emissions treatment provided by the new thermal oxidiser makes these changes unnecessary. 'I mean if we did identify a vent where we had a lot solvent coming out of it because the process was wrong it is not going to be an issue anymore because it is all going to the thermal oxidiser.' The current environmental projects being undertaken by the company reflect the low priority given to cleaner technology. The 1999 EMP listed nine projects being pursued. Only two of these, implementation of the new chemical route outlined above and pursuit of energy reductions, are cleaner technologies. The other projects are compliance and

[106] Interview with process development chemist, Pharma L, 15.9.1998.
[107] Interview with process development chemist, Pharma L, 15.9.1998.

abatement focussed: WWTP management; commissioning of the thermal oxidiser; measuring fugitive emissions; developing a Pollution Emissions Register report for the EPA, increasing the de-watering of sludge in the WWTP; achieving accreditation of for the environmental laboratory; carrying out the toxicity testing programme.

Conclusion

Pharma L considers that it has had an EMS 'in existence for many years' and 'integrated across the plant' (Pharma L EMP, EPA files, 1996). In 1997 the plant's EMS was formally accredited to the ISO14001 standard. In 1998 an EPA audit criticised the plant's programme of environmental projects, saying it should be more focussed, with quantifiable targets (Pharma L audit report, EPA files, 1997).

The plant has a strong capability in process development, and has used this resource to tackle the most pressing water effluent problems. These projects were wholly generated, developed and implemented by the R&D function without the involvement of other functions, such as manufacturing or environmental management. Projects are not driven by environmental priorities, but rather where chemists have identified promising opportunities; the view now is that they 'are approaching the tail end of the success curve.' There are no organisational systems in place whereby the environmental officer can call upon R&D as a problem-solving resource and so does not routinely consider pollution prevention as being part of the solution set for environmental problems. The effect of this can be seen in the on-going problem with emissions from the wastewater treatment plant. The plant wishes to install abatement equipment to resolve the problem despite the fact that external consultants have identified possible source reduction changes that could eliminate or reduce the emissions at source; the EPA has directed the plant to investigate source reduction further (Pharma L correspondence, EPA files, 1999).

Conclusion of Case Study Research

The presentation of the five case studies has concentrated on the development of environmental management. The intention is to gain insight into the evolution of organisational capability without abstracting away from context-specific factors. As well as drawing out the development of capability, the cases also focus on the importance of capability in determining the firm's effectiveness in adjusting to the new regulations. The capacity of plants to implement cleaner technologies is another key area of interest in the cases. In each case evidence of routines for strategic development is examined, as well as the connections between environmental strategic development and the plants' overall strategic planning. From this case study research I have drawn out four central elements of effective environmental strategic development capability: perception; integration; use of external knowledge; and routines for problem solving. Analysis of the case study findings and a full discussion of these elements, as well as integration of these findings with the statistical analysis performed on the full cohort, are presented in the next chapter.

9: Analysis of Findings

The environmental regulation of industry changed radically in 1992. A new licensing system was introduced and a new national institution was created to enforce environmental protection. Prior to 1992, under the old licensing system enforcement had been the responsibility of local government. Compliance was achieved if firms demonstrated that their pollution emissions fell within the limits set in the licence conditions. It is widely acknowledged that local authorities varied widely with respect to the competence and resources they were able to employ in regulating environmental activity. The IPC licence system introduced in 1992 has a more complex and demanding set of requirements. The EPA, as a specialised, national agency, has a high level of expertise and provides a uniform standard of enforcement. In addition to compliance with emission limit values firms are now expected to demonstrate a commitment to implementing pollution prevention technology in preference to waste treatment, to show continuous improvement in environmental performance, and to support this with procedures for environmental planning and management.

As I have shown in chapter three, the neoclassical environmental economics position is that there is no analytical value in understanding the internal firm processes of regulatory adjustment. Economically beneficial technical change does not require regulatory inducement, since a profit-maximising firm will adopt profit-maximising technical change voluntarily. Porter and van der Linde (1995a, 1995b) have developed an opposing position that environmental standards can trigger innovative, resource-efficient and economically beneficial responses by firms. However their theory is incomplete in so far as it does not explore the internal firm mechanisms that would achieve this innovation. Crucially they are unable to explain their own assertion that 'environmental regulation does not lead inevitably to innovation and competitiveness or to higher productivity *for all companies*' (Porter and van der Linde, 1995a, p. 134, emphasis added).

Adopting an evolutionary economics approach allows the use of a theory of the firm that explicitly supports the potential for regulation to stimulate technical change within firms. From this perspective, the ability of firms to meet the challenge of a new regulatory environment is dependent on their ability to deploy and, if necessary, develop the appropriate organisational capabilities.

The Importance of Organisational Capabilities

The introduction of cleaner technology in the pharmaceutical industry does not, in the main, require radical technical innovation on the part of firms. Radical innovation, as defined by Freeman (1992), 'marks a break with past production practice and experience' (p. 73), normally requiring 'new combinations of inputs, such as materials, instruments, and machinery, as well as new skills' (p. 74). The process that produces radical innovation is usually characterised by high uncertainty, chaos and diverse approaches (Rosenberg, 1992). In the wake of any successful radical innovation there are two subsequent processes of technical change. 'Existing technologies commonly throw off signals and focussing devices indicating specific directions in which technical knowledge can be usefully exercised' (Rosenberg, 1992, p. 14). This related innovation is incremental innovation, based on the same technical capabilities necessary for the original innovation and cumulative production experience, and can be 'a major source of productivity gains in many industries' (Freeman, 1992, p. 78). The second and related process is diffusion, which is the take-up of an innovation beyond its originator. Diffusion is not an automatic or simple process and is 'seldom, if ever, a simple process of replication by unimaginative imitators', as the process of adoption also requires an ability to understand and make incremental innovations to adapt the original innovation. 'The ability to *exploit* new scientific knowledge in a commercial context will depend directly and heavily upon the technical capabilities that are available within an economy' (Rosenberg, 1992, p. 18, emphasis in original).

Both incremental innovation and diffusion are involved in the introduction of cleaner technology in the pharmaceutical industry. There is a large body of knowledge on cleaner technology available to firms. Some of this information is about general principles of waste minimisation and pollution prevention, such as improvements to operational control and housekeeping. Cleaner technology as applied specifically to the pharmaceutical industry is also well understood and codified. Although each firm's production is close to unique (given patent protection), the technology employed is standard across firms: firms use a common range of basic feedstock, employing typical chemical reactions and standard equipment (Cunningham and Moriarty, 1993). It has been possible to identify common sources of waste in pharmaceutical production to which generic improvements and approaches can be applied: chemical reactions; chemical separations; materials handling and storage; operating processes such as cleaning (Cunningham and Moriarty, 1993). General principles of cleaner pharmaceutical production have been developed: minimise the number of solvents used; do not mix solvents; avoid isolation steps; avoid drying steps; optimise for the total process, not for individual reactions; recycle process washes; calculate mass balances (Johnson, 1995).

Under the terms of their licence firms are required to develop an environmental management programme of projects. The EPA explicitly requires that the programme is self-developed. To this end, beyond requiring that firms demonstrate a commitment to continuous environmental improvement, and to the use of cleaner technology over end-of-pipe, the Agency avoids imposing the direction of a firm's environmental technology programme, although all proposed projects must be submitted for approval. Where the EPA does intervene, in mandating action in relation to a clear environmental risk, they continue to try to avoid prescribing the precise technology to be used, preferring firms to learn to develop their own solutions. The EPA also has the explicit aim that the environmental management and reporting requirements of the IPC licence will foster the development within firms of processes leading to continuous environmental improvement. 'These reports play an important role in the development of an environmental strategy in the industries involved as it necessitates the examination of issues in a structured, logical manner' (EPA, 1997, p. 1). This position is supported by theories on technical change, which place significant weight on the role of managerial as well as technical capabilities (Freeman 1992, Rosenberg 1992). There is evidence, reported from industry experience with the introduction of cleaner technology, identifying the importance of managerial processes for gathering, evaluating and acting on salient information (Christie, 1997).

In technical terms, in many cases end-of-pipe and cleaner technologies are broadly substitutable, with a given outcome being achievable through either treatment or reduction/recycling. There are a number of examples of this from the EPA files. Pharma G made the strategic decision to pursue compliance with BATNEEC standards for air emission without using end-of-pipe technology; they have embarked instead on a comprehensive programme of production changes to achieve waste reduction through development of new chemical routes, changes to processes and improvements in operations. Under the terms of their licence Pharma O were obliged to reduce emissions of chloroform; they tried and failed to achieve this through process changes, and ultimately installed abatement equipment. Pharma L applied to the EPA for approval for a project to install equipment to treat air emissions from their wastewater treatment plant. The EPA referred the project back to the firm, asking them to explore waste reduction through chemical route changes instead. Pharma M invested in developing a recycling technology for one of its main waste products, and avoided both heavy disposal costs and problems with breaches of licence conditions. From these examples it can be seen that the choice of project is more a reflection of the firm's capability and/or perceptions of appropriate strategy than of specific technical constraints.

It is argued in this thesis that organisational capabilities form the basis for the firm's capacity for future activity and change. Underlying capabilities are routines, routinised patterns of behaviour which are themselves both the products of and repositories of organisational learning and knowledge (Nelson and Winter, 1982). Organisational learning is an 'intrinsically social and collective phenomenon' (Teece et al., 1994, p. 15), involving joint problem solving and coordinated 'search'. Although it may require the skills and knowledge of individuals, this still relies on 'employment in particular organisational settings' (Teece et al., 1994, p. 15) for its expression. Organisational learning is also cumulative and path-dependent; what is learnt and practised is stored in routines ('the organisational memory of the firm' (Nelson and Winter, 1982, p. 99)) and expressed in the firm's capabilities. The ability to identify, develop and introduce new capabilities has been identified as an important capability in its own right, particularly important for managing the firm's response to change; 'the term 'dynamic' refers to the capacity to renew competences so as to achieve congruence with the changing business environment' (Teece et al., 1998, p.515).

The results reported in chapter seven show that there are clear and significant differences between firms in their ability to comply with the requirements of the new IPC regulations. Firms have been asked to (i) move away from end-of-pipe technologies towards developing cleaner technology solutions to environmental control and (ii) implement processes for environmental planning and management. It might be considered that the industry would be well placed to comply with the new regulations. The pharmaceutical industry already possesses many technical capabilities that facilitate the implementation of cleaner technology.[108] Additionally, due to rigorous demands placed on them by external agencies such as the US Food and Drug Agency,[109] pharmaceutical firms already have high levels of codified knowledge about their production processes, strong process control and systems for data collection (Pisano, 1997). However, despite the availability of developed cleaner technologies and environmental management techniques and the presence within firms of appropriate technical resources,[110] firms have been differentially successful in meeting these requirements. This result highlights a limit of Porter and van der Linde's theory. In the situation where firms in the same industry, facing the same regulation, show differing abilities to respond in the direction desired by policymakers, without a theory of firm behaviour it is not possible to explain or

[108] One study identified the industry characteristics likely to facilitate successful adoption of cleaner technology as 'dynamic, research intensive and technically advanced' (ECOTEC, 1985, p. 102).
[109] FDA requires firms to comply with comprehensive manufacturing and documentation procedures (GMP).
[110] In so far as all of these firms are multinational pharmaceutical plants with access to chemical engineers, process development facilities, corporate technical resources and finance and specialised consultancy.

analyse (and therefore develop policy remedies) for these differences. In Porter and van der Linde's analysis the focus is on the regulatory instrument as the primary agent of change.

The research presented here suggests that a regulatory instrument designed to stimulate cleaner technology is not sufficient to promote change in firms. Nor is the ability to meet the requirements of the new regulations associated with either past compliance history or the possession of superior physical resources. The key finding of this thesis, based on an research into internal, firm-specific factors, is that success in being able to develop environmental management and to adopt cleaner technologies is associated with the possession of dynamic capability, measured as routines for environmental problem-solving and strategic development. Figure three provides a summary of the associations between different measures of capability.

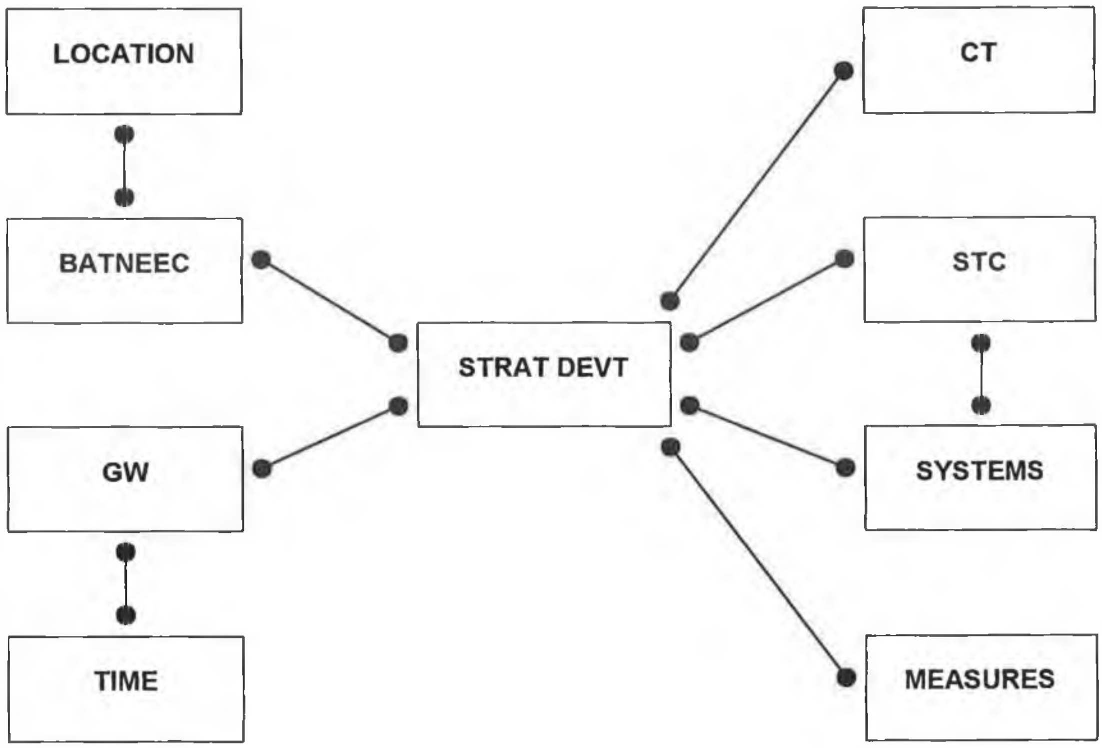

Figure 3: Map of correlations between capability indicators

Dynamic Capability and the Development of Static Capabilities

Deeper insight into the development and operation of capabilities within firms is achieved using qualitative data. From tables four and twelve, it can be seen that the firms in the cohort fall into three groups. There are firms with evidence of strong routines, scoring mostly 3 or 4 in their capability indicators. Case companies from this group are Pharma P, Pharma K and Pharma K. There are firms with evidence of some or developing routines, scoring mostly 2 in their capability indicators. No case companies were obtained from this group. There were firms with limited or no evidence of routines, scoring mostly 0 or 1 in their capability indicators. Case companies from this group are Pharma G and Pharma L.

Development of Static Managerial Capabilities

The Irish IPC licensing system is unique in Europe in that it makes explicit demands on licensees with respect to environmental management. Firms are required to develop a set of 'clear environmental goals' that must be submitted to the EPA for approval. The EPA requires that these targets are both demanding and quantifiable, so that year-on-year improvement can be measured and reported to the EPA in the annual environmental report. In addition, to support attainment of these targets, firms are required to have in place an environmental management system (EMS) that provides for document control, record-keeping and corrective actions (EPA, 1997). The EPA considers that these managerial processes are necessary to support the move towards the adoption of cleaner technology solutions and continuous environmental improvement. Quantitative indicators were developed to assess the strength of these managerial capabilities in each firm; as discussed above, the indicators show that firms were differentially able to implement the mandated managerial processes.

In the firms with strong and effective routines, the case studies showed that in early, one-off projects the opportunity was taken to retain the learning and leverage it to become the foundation for later capability. In both Pharma K and Pharma C, early experience with optimisation of wastewater end-of-pipe technology lead to knowledge and organisational processes that supported a programme of cleaner technology initiatives. In Pharma P, an early capability in environmental management was upgraded through involvement in the EMAS pilot scheme. Routines for extensive environmental measurement and subsequent goal setting have allowed the plant to leverage capability into a wide set of environmental projects. This is not the case with the firms in the other two groups. These plants have had similar early experiences with individual projects, but have not developed capabilities for environmental management.

In the second group, with respect to the use of measures and targets, the experiences of the four firms are dissimilar, but all represent incompletely routinised processes.

Pharma M is planning to introduce environmental measures. Pharma F makes limited use of measures in only one area. Pharma E measures environmental impact in a number of areas but does not use these measures as a basis for environmental target setting and improvement. Only Pharma A has strong routines for the use of environmental measurement. Similarly with routines for environmental management, there is a range of behaviours. Pharma M is still developing processes. Pharma F has a formal EMS, but it is focussed on processes for management of waste abatement. Pharma E's EMS has been identified as inadequate by EPA auditors. In Pharma A there is evidence only of systems for quality management, and initial plans for the development of an EMS. In the third group, the failure to develop capability can be seen clearly from the indicators, and the underlying rationale presented in table 4. These firms have not progressed beyond single measurement exercises. Environmental management systems are either unsubstantiated plans for the future, or minimal formal systems that do not drive cleaner technology adoption or continuous environmental improvement. Without detailed case study data it is not possible to draw more than limited conclusions about the factors operating in the second group of plants. What can be said is that while the plants in the third group display little evidence of routines, in the second group there is evidence that attempts are being made to develop or plan for routines.

In the firms with strong capabilities we can see that the EPA's intended relationship, where managerial processes support cleaner technology take-up, works as the Agency intended. However, the EPA's prediction that the requirement for managerial processes would act as a driver for cleaner technology development is not supported by the research. Firstly because firms struggled to implement managerial changes as much as technical changes. Secondly because the development of technical capabilities is not associated with strong managerial capabilities, but rather both are independently associated with the possession of capabilities for strategic environmental development.

Development of Static Technical Capabilities

Analysis of correlation coefficients also found a statistically significant association between the possession of dynamic capability and the level of cleaner technology take-up. As well as differences between firms in the ability to adopt cleaner technology, there are differences in the types of technology adopted. All firms have adopted cleaner technology projects, suggesting that all firms have at least some skills and knowledge of cleaner technology, or have gained access to the skills and knowledge of external consultants. This we would expect, given the general technical competence of the pharmaceutical industry.

However, some firms display routinised patterns of cleaner technology capability; they have developed related projects drawing on the same techniques and areas of experience. Other firms have adopted cleaner technology without specialising in any particular approach. There are also firms that are still reliant on end-of-pipe approaches. Again, the possession of dynamic capability was associated with the leveraging of technical knowledge into a specialisation in a particular type of cleaner technology project. Weak or absent dynamic capability was associated with a concentration on end-of-pipe abatement technologies.

Strong routines for problem solving and strategic development drive continuous environmental improvement and the pursuit of cleaner technology take-up. The firms in group 1 have established organisational processes that systematically search for environmental problems and generate programmes of projects to improve pollution prevention. These projects are tackled using established cross-functional, continuous improvement teams, supported by on-going relationships with corporate and external sources of advice and expertise.

The firms in group two have evidence only of one-off problem-solving initiatives. What is missing is any evidence that this activity is routinised into established organisational processes that drive ongoing pursuit of cleaner technology. Some of these firms have processes in place to identify environmental impacts, but again these are not integrated into processes to translate this information into related improvement projects

The firms in group three are not only characterised by the absence of the routines described above, but they also demonstrate evidence that this lack of capability has adversely affected their relationship with the EPA, ultimately leading to reduced flexibility of action. Problems such as incorrect interpretation of regulations, refusal of approval for proposed environmental projects, mandated changes to organisational processes, unannounced visits by EPA auditors, and ultimately prosecution are all examples of how, in these plants, weak environmental management capability acts as a costly constraint on plant management.

Role of Dynamic Capability

Firms with strong routines did not necessarily begin their environmental management development earlier than the weaker firms (table 23). In none of the firms did significant initiatives predate 1989, and most firms, in all groups, only began to implement changes at about the time that the industry would have become aware of the proposed IPC legislation. As reported in chapter seven, there is no statistically significant correlation between the development of strong environmental management routines and the possession of superior physical resources.[111] Nor are firms that had achieved BATNEEC standards in advance of receiving an IPC more likely to be successful in implementing strong environmental routines. The success of regulatory compliance among the firms in group one does not appear to be explained by recourse to any quantitative factors. The explanation lies rather in the qualitatively different experiences or evolutionary paths of these firms. Despite starting from a similar position to the other firms in the cohort, these firms made more of the opportunities presented. In the case study research I was able to unpack the dynamic capability for strategic development and identify elements that supported firms in developing environmental management systems and introducing cleaner technology. These elements are discussed under the headings of perception; integration; accessing external knowledge; and routines for problem-solving.

[111] Correlations were carried out with (i) firm size and (ii) process development resources.

Firms with Evidence of Strong Routines – examples from case study firms		
Pharma P	1989	Award for environmental management
	1992	Approached to join EU EMAS pilot scheme
	1994	Undertook first major waste minimisation project
	1996	Undertook utilities reduction project
		Established waste minimisation group
	1997	Achieved EMAS accreditation
Pharma C	1988	Introduced first corporate environmental strategy
		Set goal of chlorinated solvent elimination in 10 years
	1989	Appointed environmental manager
	1991	Established separate environmental function
		Undertook major solvent reduction project
		Introduced use of environmental measures
	1992	First annual corporate environmental report
	1993	Participated in corporate waste minimisation project
	1997	Achieved ISO14001 accreditation
Pharma K	1989	Undertook major waste evaluation project
	1991	Issued corporate environmental policy
		Issued corporate guidelines on waste minimisation
	1992	Investigated solvent recycling
		Established waste minimisation working group
	1996	3 year plan to pilot EMS corporate standard
Firms with evidence of some or developing routines – examples from EPA files		
Pharma E	1991	Introduced ongoing solvent reduction programme
		Began use of eco-indices
	1994	Established environmental department
	1996	Introduced environmental policy
Pharma F	1978	Commissioned baseline environmental studies
	1991	Developed environmental strategy
		Introduced environmental policy
		Implemented Environmental Quality System
	1994	Established waste minimisation programme
		Established energy committee
Firms with limited or no evidence of routines – examples from case study firms		
Pharma G	1990	Set corporate goal of 90% emissions reduction through equipment upgrading
		Introduced environmental management programme - equipment upgrading and environmental training
		Part of corporate emissions reporting system
	1994	Undertook waste stream evaluation project
Pharma L	1991	Established R&D waste minimisation committee
	1994	Appointed an environmental officer
	1997	Achieved ISO14001 accreditation

Table 23: Key dates in environmental management development of firms

The five case studies fall into two groups. The firms Pharma P, C and K had adapted smoothly to the requirements of the IPC licence smoothly. Although compliance had required change and effort by the firms, there had not been any significant delays or problems. The second group, the firms Pharma G and L, has struggled to make the changes required by the new licensing. They both suffered delays in the licence applications due to lack of information. Pharma G has ongoing problems with the local community and Pharma L has had difficulties in meeting its licence conditions.

Perception: Penrose (1959) suggested that what an organisation was able to do in the future was shaped by experience gained from past growth. But further than this she argued that past experience shaped managers' image of the opportunities open to the firm. Teece et al. describe this as 'a firm's past experience conditions the alternatives management is able to perceive' (1997, p. 524). Hodgson (1996) draws the distinction between information and knowledge; information becomes knowledge only after interpretation, and the same information may not provoke the same knowledge, the difference being the interpretation performed by the firm's cognitive framework or perception, or 'knowledge is processed information' (Fransman, 1994, p. 717). In the five case firms it was clear that, in response to the same external regulatory demands, they each had a different perception and interpretation of what was required to develop their environmental performance to the necessary standard.

In Pharma P, the perception is that the plant benefits from taking up opportunities to maximise and exploit learning and also that environmental excellence benefits the plant. In Pharma C the perception is that an integrated, cross-functional approach to continuous improvement is key to maintaining the plant's competitiveness within the corporation; environmental management, as a fully integrated site function, has a role to play in achieving increased efficiency through cleaner technologies. Pharma K's strategy is driven by the belief that a high level of environmental control is important to the plant's ongoing survival, and that increasing control is best achieved through pollution prevention, not abatement. In the successful firms their 'image' was congruent with the development of cleaner technology and processes for continuous improvement and included the integration of environmental management with overall strategic development.

Pharma G's view is that 'legislation only requires control'. They point to their substantial investment in abatement technology, allowing them to achieve emissions levels far below the levels set in their licence, as proof of their commitment to environmental excellence. At plant and corporate level pollution prevention is interpreted as being emissions reduction achieved through abatement. The environmental manager has no formal involvement in pollution prevention. Pharma L similarly perceives a limited role for the environmental management function in driving forward cleaner technology projects. Environmental improvement is characterised by the company as a function of equipment and investment, rather than the use of experience or capability. Again, the plant points to its large investment in abatement technology as an example of commitment to environmental improvement. In both Pharma G and E the perception is that opportunities for future cleaner technology projects are limited; the reasons given are that the projects that have been carried out are seen as sufficient and as having exhausted all opportunities. In both plants the function of environmental management is to ensure compliance with minimal disruption to the core activities of the firm.

Integration: Pharma P, B and C routinely put together projects that relied on inter-departmental teams. This has been identified in the organisational capabilities literature as an important competence that allows for leveraging knowledge from different areas. Henderson (1994) defines integrative capability as the ability to integrate fragmented knowledge across boundaries within a firm; this capability shapes the control of information within the firm and the structuring of 'organisational attention' (p. 608). Within the cleaner technology literature it has been identified as being important for developing cleaner technology solutions, which are not restricted to one area and discipline (such as end-of-pipe, engineering solutions for waste treatment) but cover the whole production process and a multiplicity of approaches (Christie, 1995; Jackson, 1993). It also serves to build environmental awareness and capability within other functions, such as manufacturing and process development. In Pharma G and E there is limited formal integration; the perception is that environmental management is a support function and a priority is not to disrupt the main business of production. Cleaner technology projects are carried out, but without the involvement of environmental management. These projects are often primarily undertaken for efficiency reasons, with environmental benefits a side effect rather than a driver.

Accessing External Knowledge: Pharma P, B and C all made effective use of knowledge accessed from external sources. Cohen and Levinthal (1990) argue that this is an absorptive capacity, the ability to 'recognise the value of new information, assimilate it and apply it to commercial ends' (ibid., p. 128) and is an element of a firm's organisational capabilities set. It is 'largely a function of the level of prior related knowledge' and is developed from the intensity and accumulation of past learning. Pharma P and B have both employed the Clean Technology Centre to help with the development of projects, and in both cases the knowledge has been successfully integrated and used to upgrade the firm's own capabilities. Pharma K has worked with the corporate environmental laboratory to increase its understanding of solvent recycling. Routines for the development of solvent recycling in new products have been successfully transferred from the corporate function and replicated at the plant. Pharma G and E considered that the plant's own, internal resources were better than any external advice; in both firms there were examples of external advice that had been sought, but ultimately not implemented.

Routines for Problem-Solving: Pharma P, B and C have all established effective organisational patterns for examining environmental performance, determining priorities and developing solutions. Pharma P uses a site profile combined with a management review process to determine areas for development. Pharma C uses a combination of corporate priorities and the site management review to determine goals, and the plant continuous improvement process teams to develop solutions. In Pharma K an inter-departmental task force has evolved to evaluate waste streams and manufacturing processes and develop technical options. No such formal processes operate in either Pharma G or E. In Pharma G the only formal assessment of environmental priorities was a one-off project to review waste treatment. Cleaner technology projects, such as source reduction and solvent recycling, appear to be the responsibility of individual departments. In Pharma L pollution prevention is primarily the responsibility of the Process Development function. It takes place as part of ordinary process development work on new processes, and has in the past been undertaken in response to a severe compliance issue. The plant does not have organisational routines whereby management assesses environmental impacts as a basis for planning future environmental management strategy.

Resources

The differences between the firms in their ability to develop effective organisational processes for environmental management and cleaner technology are not attributable to human or technical resources. Both Pharma G and E are large multinational firms, with the potential to access corporate environmental and R&D knowledge and advice. Nor are there significant differences between the two groups in terms of the resources available in environmental management. All firms have an environmental manager/officer with responsibility for regulatory compliance and maintenance of the environmental management system. In addition there are two or three operators assigned to the abatement equipment, as well as two chemists responsible for testing and monitoring of emissions. The difference between the two groups is also not attributable to capital availability. Pharma G and E have both made large-scale investments, of at least £15m each, in environmental (abatement) technologies.

Given the importance for cleaner technology of understanding of the production process, it might be expected that firms with a strong process development capability would demonstrate an advantage in implementing cleaner technologies. This is not supported by the case study research. Pharma P was able to develop chemical route change projects without having a strong process development capability. Pharma G and E are both lead plants within their corporations for the introduction of new products; they have significant physical and human resources invested in technology transfer, pilot plants and process development capabilities. This finding is supported in the analysis of the cohort of 16 firms, where it was found that there is no statistically significant correlation between the strength of a firm's process development function and either the percentage of reported projects that are cleaner technology projects or the pursuit of List I/II projects. Both of these indicators are however positively and significantly correlated with the possession of organisational capability for problem solving and strategic development.

Firm-specificity in Environmental Management

I have described the case studies in terms of two groups with common characteristics. It should also be clear from the individual case studies that each firm approaches environmental management in an idiosyncratic way, based on the path-dependent development of environmental management at the plant, the influence of external events and the experience and perceptions built over time. Within the three more successful cases there are differences in the management approach and in the types of technological solutions implemented. These firms differ in the nature of corporate relations; Pharma C and C receive strong corporate support, whereas Pharma P is an environmental groundbreaker within its corporation. It is also possible to draw out the way that firms can respond to similar events in very different ways. Both Pharma K and Pharma G have experienced problems with emissions that engendered negative relations with regulators and the community that threatened to act as a constraint on the plant. In one firm this provoked a strategy of proactive environmental control and community relations; in the other a more defensive response was seen.

In conclusion, dynamic capability in these case companies involves both tacit and explicit elements. The firms with effective capability are characterised by the presence of routinised processes that have been put in place as the result of strategic action. These processes are for planning change, for reflecting on past performance, for embedding and routinising learning, and for leveraging knowledge. However, there is a significant tacit, experiential and path-dependent element to environmental management strategy in these firms. Why these firms made decisions to pursue effective strategies, and other firms made equally deliberate decisions to follow different strategies seems to be in large part shaped by each firm's perception of the opportunity set it faces. This accords with the description of dynamic capability put forward by Zollo and Winter: 'dynamic capabilities emerge from the co-evolution of tacit experience accumulation processes with explicit knowledge articulation and codification activities' (2001, p. 19).

Significance of the Research and Findings

Implications for Study of Environmental Policy

The thesis makes a strong theoretical and empirical contribution to the debate on regulation-innovation relationship. The research presented in this paper show that firms are differentially able to respond to technology-forcing regulations and that these differences are associated with differences in organisational capabilities. Any attempt to understand and analyse the potential for environmental regulation to promote both environmental protection and enhanced productivity requires an understanding of internal firm behaviour. The failure of both neoclassical environmental economics and Porter's theory to provide convincing analysis is rooted in their failure to look inside the black box. The evolutionary theory of the firm, with its emphasis on organisational capabilities as the driver of technical change in firms, provides a framework for the development of a coherent model of the relationship between environmental regulation and firm technical change.

There are also policy implications arising from this research. The aim of the IPC regulation is to encourage continuous improvement in environmental performance. The legislation recognises that cleaner technology represents an opportunity to overcome the technical and economic constraints of end-of-pipe approaches. The legislation also recognises the organisational element of continuous environmental improvement, and firms are therefore required to implement systems for environmental management and measurement, with the intention that this will stimulate problem-solving and technical change within the firm. My research shows that firms will struggle to implement organisational change as much as technical change. Furthermore, the organisational processes identified by the regulators do not appear to be associated with higher use of cleaner technology. The research identifies that the firms that have mastered both elements of the EPA's strategy, cleaner technology and environmental management, already possess a capability for problem-solving and change. From the case studies it can be seen that it is possible for firms to achieve minimal compliance with the EPA's stated requirements for management systems without developing an integrated problem-solving capability. This compliance is static in nature, that is, firms comply with requirements as they stand now. It seems however unlikely that the EPA's goal of continuous environmental improvement will be achieved by these firms, particularly if the firm's perception of environmental performance has an explicit compliance and abatement focus. Furthermore given that the key dynamic capability has evolved out of firm-specific learning and past experience, remains the basis for durable differences between firms and cannot be acquired, clearly there are limits to the ability of regulation to stimulate firms to undertake technical change in a desired direction.

Importance of Abiotic Competition

The research has broader implications for the study of organisational capabilities and strategic management. Issues of strategy and competitive advantage are generally discussed in the context of competition between firms in an industry. Even where writers use a definition[112] that encompasses the notion of addressing or neutralising competitive threats from the firm's external environment, this aspect of competition has not received any great focus in the strategic management or industrial economics literature. In this research the role of organisational capabilities in determining firm behaviour in non-core areas of activity is established. Environmental management is not a core competitive issue for these firms; however, through the existence of formal

[112] Such as that used by Kirsten Foss, 'resources are *valuable* to a firm if they enable the firm to implement strategies that exploit opportunities or neutralise threats in it environment' (1996, p. 139, emphasis in original)

and tacit[113] licences to operate, environmental management has a strategic importance in so far as it can operate as constraint on the flexibility of action enjoyed by plants.

I am arguing in this thesis that attention should be paid to areas, not traditionally thought of as being connected to competitive advantage, where firms must act strategically to ensure survival through securing 'fit' with the demands of the external environment. The distinction was drawn clearly by Darwin between biotic competition and abiotic competition. Biotic competition, or competition 'directly against other organisms for limited resources' is familiar to us as Darwin's 'survival of the fittest' (Gould, 1997, p. 142), and analogous to competition between firms in an industry. Darwin developed the concept of abiotic competition, competition 'against the rigours of the physical environment', and described by Darwin as 'the struggle for existence' (Gould, 1997, p.142).

> I should premise that I use the term Struggle for Existence in a large and metaphorical sense.... Two canine animals in a time of dearth may be truly said to struggle with each other which shall get food and live. But a plant on the edge of the desert is said to struggle for life against the drought (Darwin, 1859, p. 62, quoted in Gould, 1997, p. 142).

Abiotic competition is an element of natural selection; the shaping of organisms by the limiting factors of the physical environment. I am arguing that for industry, and for capability research, this may be as important as the more commonly seen focus on narrowly defined competitive factors (such as capabilities for R&D and new product introduction). 'One may distrust the basic assumption that of IO-inspired strategy thinking that firms are constantly engaged in playing games against each other. Instead, it may be asserted that a larger part of firm's activities concern games against nature' (Foss, 1996, p. 184).

Understanding of Dynamic Capability

The thesis contributes to increased understanding and refinement of the use of organisational capabilities within evolutionary economics, as well as adding to the thin empirical base of organisational capability research. The organisational

[113] That is, community consent to industrial operations.

capabilities literature has struggled to develop a categorisation for 'organisational patterns', to identify the relationships between different components of capability or even to establish the appropriate level of analysis. In this research I distinguish historical and contemporary indicators for technical, static organisational and dynamic capabilities on the basis of measures inferred from performance outcomes, developed using a unique data set. This has allowed for the development of capability indicators that are more detailed than could have been achieved through survey research, across a wider range of firms than could have been achieved by case study research.

Furthermore, by surveying the whole sector, and by carrying out research on mandated capability the research provides insight into the absence of capability. Success in the competitive environment can be achieved through different capability sets, whereas in this context the regulations throw the absence of capability into stark relief, as firms do not have the possibility to compensate for lack of capability with an alternative capability set. This addresses a gap in the literature concerning the implications of the absence of capability Another benefit afforded by studying capabilities in this context is that environmental management is not considered to be a source of competitive advantage in this sector. Most empirical research is carried out on capabilities for competitive advantage, where firms work actively to prevent the diffusion of valuable capabilities. Environmental management is not a source of competitive advantage for these firms[114] and they do not attempt to build barriers to imitation. This makes the failure of some of the firms to develop capabilities all the more striking and lends weight to the view that the creation of capability cannot be directly influenced, either by regulators or by firms themselves.

The literature argues that technical capability is a reflection of path-dependencies in experience and learning, leading to constrained technology opportunities. Firms have been using abatement technologies for over 30 years; cleaner technologies have only begun to be adopted widely since the 1990s. The empirical research identified firms

[114] Consumers of pharmaceutical products do not value green products; cost-reduction is not a significant competitive factor, as manufacturing costs are a fraction of R&D and marketing costs.

that were strongly specialised in a particular type of technology, both abatement and cleaner technologies. The research also pointed up the inter-relationship between organisational and technical capabilities: firms that remain specialised in abatement technologies are firms that have weak problem-solving capabilities. The case study research showed that firms with strong problem-solving capability were able to adopt cleaner technology projects in areas outside their previous experience: Pharma P and chemical route change; Pharma K and solvent recycling.

The key finding from the empirical research is that possession of a strong dynamic capability is associated with achieving a high level of performance of all of the other indicators. This was supported in the case study research, which demonstrated that, in the cases studied, weak dynamic capability is not only associated with a failure to adapt to new regulations, but also a failure to anticipate and resolve environmental problems historically. These firms were characterised by low organisational attention to environmental management and a reliance on bought-in knowledge (as embedded in abatement technology), with low preparedness and an inability to prevent environmental issues acting as a constraint on the firm. Firms with high performing dynamic capability were able to ensure effective environmental performance, preserving flexibility of action and supporting overall competitiveness.

From the literature, the expectation was that in a changed regulatory environment, calling for a change in technology and organisational processes, firms would find it difficult to respond if they did not possess the requisite capabilities. 'Organisations are poor at improvising coordinated responses to novel situations; an individual lacking skills appropriate to the situation may respond awkwardly, but an organisation lacking appropriate routines may not respond at all' (Nelson and Winter, 1982, p. 125). What the research found was that the presence or absence of appropriate static capabilities, either technical or managerial, did not matter if firms possessed dynamic capability. Teece et al. point to the central role of dynamic capabilities in managing change: 'We define dynamic capabilities as the firm's ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments' (1997, p. 516). In this research, almost all other indicators of environmental management were significantly correlated only with the dynamic capability indicator. The development of this dynamic environmental development capability appears to predate the introduction of IPC licensing, in that it is also correlated with the presence of historical indicators of environmental capability[115] relating to environmental management under the previous licensing system. This suggests that the importance of dynamic capability is not restricted to underpinning effective performance only in changing environments.

It is useful at this point to refer again to the caveats expressed above about the distinction between correlation and causality. Henderson and Cockburn advise that as 'organisational competencies are probably composed of several tightly linked complementary activities' any measures developed 'are best interpreted as "symptoms" or "indicators" of the presence of ...competence, rather than as causal variables' (1994b, p. 72). Bearing this in mind, what can be said is that firms that possess routines for environmental strategic development are firms that were successful in meeting their environmental responsibilities under the previous, emission-focussed legislation, and have also been successful in adapting to a very different set of requirements under the new regulatory environment.

Organisational capabilities are defined as being path-dependent, the by-products of past experience and learning. At the outset of the research it was anticipated that an association would be found between good environmental management and compliance in the past and successful adaptation to the new regulations. This did not appear to the case. Again, the possession of dynamic capability, with some evidence that this capability predates or exists independently of the regulatory environment, was the only significant factor associated with successful IPC compliance. Dynamic capability appears to give firms the ability to overcome the negative or 'core rigidity' (Leonard-Barton, 1992) aspect to path-dependent capability. The case study firms that had strong routines for problem-solving and strategic development were not

[115] The relevant indicators are BATNEEC and GW.

restricted to a set of technical opportunities constrained by previous experience and current knowledge.

In this way capability can be seen to enable strategic behaviour, rather than purely automatic or deterministic responses, as firms were able to identify and accumulate capability in new areas. However, this is not to deny the tacit, experiential and path-dependent nature of capability, static or dynamic. Nelson and Winter (1982) identified two drivers of change. As well as the deliberative processes of 'search', that is, directed learning and development of new patterns of behaviour in order to meet strategic requirements they recognised the impact of random, unanticipated events resulting in learning and new experience. Zollo and Winter's (2001) extension of this work concentrates on the intentional elements of dynamic capability, that is, knowledge articulation and codification, while acknowledging that the tacit is also important. A little explored question from the literature relates to the absence of capability. If the definition of capability is that it is the accumulation of learning and experience, this implies that potentially all the firm's past experiences will become embedded as routines and capability. This suggests that all firms will have capabilities, the difference being that not all firms will have the capabilities that provide for success in a given environment. The evidence of this thesis is not that firms have good or bad environmental capabilities, but that some firms have capabilities, where others appear to have limited or no capabilities for environmental management. The research using capability indicators showed that the difference lay with the presence or absence of routines for identifying, developing, leveraging and embedding new knowledge, analogous to the processes identified by Zollo and Winter (2001). The role of reflexive action may explain why not all experience gets translated into capability and some firms may not possess any capability in a given area.

This finding was supported by the case study research, which also identified an important difference between firms in terms of the way environmental management responsibilities and opportunities were framed. I would argue for increased recognition of and attention to the importance of perception[116] as the significant tacit element of dynamic capability. In this research the successful firms were characterised by the possession of strong processes for 'collective learning' (Zollo and Winter, 2001, p. 10) and were able to 'achieve an improved level of understanding of the causal mechanisms intervening between the actions required to execute a certain task and the performance outcomes produced' (ibid., p. 10). However, from the case study research, it could also be seen that underpinning and shaping these processes was a strong tacit, experience based influence in the form of the perceptions held by the firm that preceded and influenced the decision to implement processes for knowledge codification and articulation.

[116] Penrose's concept of "image" (1959).

10: Conclusion

This thesis looks at the potential for environmental regulation to induce economically beneficial technical change in industrial activity. The question is explored in the context of the introduction of new regulations for the licensing of the environmental impact of industrial activity in Ireland. Central to the IPC licensing philosophy is continuous improvement and a shift of emphasis to pollution prevention rather than pollution treatment. Firms are required to meet standards for the emission of pollutants, but above that they are also required to demonstrate a continuous effort to upgrade their environmental performance. To support these changes, the regulators require that firms put in place environmental management and information systems and establish an environmental management plan (EMP) that sets goals and reports on progress. Firms that are able to respond to the new requirements by developing effective environmental management will be able to avoid the threats associated with non-compliance from both the regulator and the local community. By implementing cleaner technologies, these firms will have an advantage in managing the costs of compliance and the demands of future regulations. They will benefit from enhanced reputation and risk management. There is also the potential to develop and upgrade technical capabilities that support strategic advantage. On the other hand, firms that do not develop an effective organisational response to the new legislation will face forced rather than planned change and severe limits on their flexibility of action.

A number of economics literatures were examined in order to determine the best theoretical basis for pursuing the research. The dominant analysis of the impact of regulation on industrial performance has been neoclassical environmental economics. I suggest that neoclassical environmental economics can be criticised on two levels. On a general level the neoclassical economics research programme can be criticised for its mechanistic characterisation of environment-economy interactions and its willingness to separate consideration of the environmental constraints on economic activity into a sub-discipline. At a more specific level it can be criticised on the grounds of the inadequacy of its models to analyse the impact of regulation on firm behaviour. The theory generally assumes that regulation is a constraint on firms' behaviour and the firm's decision to innovate is assumed to be made by applying profit-maximising criteria to a perfectly known set of innovations. Because of these assumptions there has been no systematic consideration of technical change in empirical investigations of the regulation-competitiveness relationship. Using the neoclassical model of a profit-maximising firm with perfect information, neoclassical environmental economists argue that profit-maximising cleaner technology will be adopted by profit-maximising firms without requiring a regulatory stimulus and moreover, regulation can only act as a constraint on firms.

This finding has meant that there is little interest in exploring the impact of innovation on environmental performance. The exclusive focus on the superiority of market-based instruments has meant that the potential for other types of regulation to induce technical change with economic and environmental benefits is assumed away. Neoclassical environmental economists reject the possibility that regulation can generate a 'win-win' solution, achieving both environmental protection and economic gains. This position has been challenged by Porter, who claims that that 'environmental standards can trigger innovation' (Porter and van der Linde, 1995b, p.98) leading to both social and private gains. The argument is that cleaner technology can become a tool for achieving increased efficiency and can support strategy in the face of the demands of dynamic competition for continuous technical change and innovation at both product and production levels. Porterian firms cannot pursue profit-maximising behaviour; they face problems of information, control and organisational inertia. The nature of dynamic competition means that they face problems with the rapidity of change in technical knowledge and in the opportunities open to them; firms are learning institutions in an environment that is characterised by both high uncertainty and the need to innovate in order to compete. Firms require a regulatory stimulus to alert them to the potential for improved competitiveness because of limited managerial attention, lack of experience and organisational inertia.

I concur with Porter and van der Linde's rejection of the neoclassical environmental economics position that there is no analytical value in understanding the internal process of regulatory adjustment. However their theory is incomplete in so far as it does not explore the internal firm mechanisms that would achieve this innovation and the research fails to demonstrate robust theoretical evidence of a positive relationship between environmental regulation and firm competitiveness. Crucially they are unable to explain their own assertion that 'environmental regulation does not lead inevitably to innovation and competitiveness or to higher productivity for all companies' (Porter and van der Linde, 1995a, p. 134).

This thesis explores the potential of the evolutionary economics theory of the firm for application to the analysis of environmental regulation of industry. Like Porter, evolutionary economists contend that neoclassical theory is fundamentally unable to analyse economic change. Similarly, the theory contends that neoclassical theory is hampered by the very foundations on which its assumptions are based, and which deny the main features of change. Evolutionary economics explicitly recognises that processes of economic change and technical innovation are characterised not by perfect information and instant adjustment but by searching, by trial and error, by learning over time and by elements of chance. However Porter explicitly assigns primacy to determinants external to the firm and so does not possess a framework of firm behaviour within which to explore these relationships. Any attempt to understand and analyse the potential for environmental regulation to promote both environmental protection and enhanced productivity requires an understanding of internal firm behaviour. The failure of both neoclassical environmental economics and Porter's theory to provide convincing analysis is rooted in their failure to look inside the black box.

The evolutionary theory of the firm, with its emphasis on organisational capabilities as the driver of technical change in firms, provides a framework for the development of a coherent model of the relationship between environmental regulation and firm technical change. In the evolutionary theory of the firm organisational capabilities and growth opportunities coevolve. The firm is a 'knowledge creating entity' (Foss, 1996b, p. 191). Experience develops the productive capacity of the firm and shapes its unique strengths. In turn, the nature of existing capabilities will influence the perception of and capacity for future growth. Organisational capabilities are the basis for persistent firm heterogeneity. Where they underpin fitness with the firm's environment the result is differential rates of growth and survival. 'Firms are seen essentially as repositories of competence' and it is the 'firm's ability to accumulate, protect and deploy competences' (Foss, 1996a, p. 1) that determines long run success.

Organisational capabilities, as the embodiment of tacit and context-dependent knowledge, are, by definition, difficult to observe and therefore measure. Capabilities are expressed through routines (Nelson and Winter, 1982) defined as 'the way things are done in the firm... or patterns of current practice and learning' (Teece et al., 1998, p. 518). 'It is the routines themselves and the ability of the management to call upon the organisation to perform them that represents an organisation's essential capability' (Teece et al., 1994, p. 15). This research uses the presence of observable static and dynamic organisational routines for environmental technology, management and strategic development to infer the presence of capabilities. Technical competency in cleaner technology take-up and organisational processes for environmental management and measurement are static capabilities, that is, they are capabilities that allow the smooth and efficient performance of tasks. The strategic development capability is a dynamic capability, a capability for developing new capabilities. I have developed measures of capability, based on information reported to the regulatory authority. This supports comparative analysis of the role of organisational capabilities in the sector's response to new environmental regulations. Further analysis of questions around the origins, significance and contingent nature of capabilities is explored in qualitative, case study research. The combination of the two research approaches allows for a full exploration of both the development and the implications of organisational capabilities.

The conclusions of the research are that firms are differentially able to respond to the new requirements of IPC legislation. This difference is associated with the presence of organisational capabilities for environmental management. Specifically, successful compliance with the IPC regulations is associated with strong routines for environmental problem-solving and strategic development. Firms with these routines are more likely to have a high level of cleaner technology adoption and are also more likely to have routinised processes for environmental management and environmental measurement. This finding has policy implications, indicating that the ability of policy to change firm behaviour in desired directions is constrained by the mediating influence of organisational capabilities.

The research makes a contribution to the organisational capabilities literature. It adds to the body of empirical capability research, providing both new methods for identifying and measuring capability, as well as support for the central proposition that capabilities are the source of durable differences in firm performance. Research in this area has traditionally focussed on areas related to competitive advantage. This thesis extends the research and shows that organisational capabilities affect firm behaviour in areas not directly associated with competition. I argue that this strengthens the findings by showing that the tacit and inimitable features of capability hold even where firms are not intentionally trying to hinder diffusion. I also argue for the importance of a broader understanding of competitive advantage. I introduce the concept of abiotic competition, that is, competitive struggle not with other firms but with the external environment. This research makes a case that firm performance in respect of strategic fit with the external environment is an important and overlooked area of study.

The research also represents a contribution to the growing body of research on the nature of dynamic capability. The research identifies the central role of dynamic capability, and suggests that, contrary to arguments in the literature (Teece et al, 1998), dynamic capability's critical role is not restricted to changing environments but may underpin *all* effective performance. It is argued here that dynamic capability is a function of both the tacit perceptions held by a firm (arising out of past experience and learning) and deliberative, problem-solving processes. This represents a refinement of existing approaches to dynamic capability, and argues for increased importance to be given in research to the role of firm perceptions. A novel contribution is the development of insight into the absence of capability, addressing a significant gap in the literature. The nature of the firm's perception has an influence on the presence or absence of reflexive and deliberative processes of learning and change, resulting in the failure or success in developing capability and achieving effective performance.

The research concludes that, in a changing environment, the most important factor for successful adaptation is the ability to identify and implement new learning, new kinds of knowledge and new organisational processes, but that this will only happen where the firm's perceptions of future opportunity support such a strategy.

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Appendix A:

Calculations of Spearman rank-order correlation coefficient (Siegel, 1988, p. 235)

	GROUP	PD	S/DEVT	MEAS.	SYS	CR	LIST I/II	BATNEEC
GROUP	1.0000	0.2052	0.7253	0.7518	0.6548	0.1522	0.4004	0.9211
PD		1.0000	0.0786	-0.1051	0.4367	0.6181	0.0713	0.2970
S/DEVT			1.0000	0.8266	0.8452	0.2368	0.7011	0.6719
MEASURES				1.0000	0.5862	-0.0944	0.5574	0.6459
SYSTEMS					1.0000	0.3570	0.5245	0.6740
CR						1.0000	0.3770	0.1377
LIST I/II							1.0000	0.2593
BATNEEC								1.0000
WET								
TIME								
LOCN								
GW								
CT								
STC								
SIZE								
WET-NO								

CRITICAL VALUES	
$p<0.10$	0.3410
$p<0.05$	0.4290
$p<0.01$	0.5820

WET	TIME	LOCN	GW	CT	STC	SIZE	WET-NO
-0.4582	-0.3073	-0.4109	0.4638	0.4916	0.6692	-0.0890	-0.2436
-0.1215	0.1280	-0.1321	-0.1383	-0.0512	0.4410	0.2280	0.1249
-0.8186	-0.5205	-0.1734	0.6273	0.8056	0.7065	-0.3840	-0.6432
-0.7092	-0.3057	-0.2107	0.4209	0.7415	0.6924	-0.4358	-0.5944
-0.6745	-0.3080	-0.1372	0.4454	0.6175	0.7722	-0.2399	-0.4574
-0.1735	-0.3197	0.1059	0.0881	0.2055	0.3834	0.2478	0.1678
-0.6159	-0.6287	0.0774	0.4305	0.6163	0.3627	-0.3156	-0.3240
-0.3556	-0.3421	-0.5154	0.4619	0.3011	0.7367	-0.1086	-0.2191
1.0000	0.2255	0.1172	-0.1990	-0.8312	-0.5672	0.4952	0.8732
	1.0000	0.3204	-0.5097	-0.3931	-0.2779	-0.0310	0.0723
		1.0000	0.1349	0.1173	-0.2340	0.0583	0.0934
			1.0000	0.5416	0.2615	0.0406	-0.2351
				1.0000	0.5367	-0.1586	-0.6768
					1.0000	-0.2255	-0.3679
						1.0000	0.5557
							1.0000