Technology Development in Ontario's Environmental Technology Industry: Towards a Model of the Environmental Regulation-Innovation Relationship

by

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ABSTRACT

The environmental technology industry is targeted under the strategic industrial development plans of both the federal and provincial governments in Canada. The promotion of this industry is driven by the belief that environmental regulations can contribute to industrial development by creating new industries dedicated to the development and manufacture of environmental compliance technologies. Although this view is common in some academic and policy circles, the reality is that there is little empirical or case study analysis to support (or dispute) this hypothesis. In contrast, the evidence that does exist tends to focus on the behaviour of regulated firms while failing to evaluate the performance of environmental technology suppliers.

Responding to this shortfall, this dissertation examines the relationship between environmental regulation and the firms who develop and manufacture of environmental technology. A model of the environmental regulation-innovation relationship is developed, and this is tested empirically thorough a survey of the manufacturers of water and wastewater technology in Ontario.

The research findings indicate that environmental regulations act to stimulate the development of environmental technology. However, the regulatory stimulus is channeled through firms subject to the regulation rather than directly to the water and wastewater technology firms. The innovation strategies of the technology producers are more directly influenced by the regulatory

needs of their customers, as a result, the impact of environmental regulations are mediated by user requirements.

The analysis also indicates that the water and wastewater technology firms have successfully established a collaborative relationship with their customers. This collaboration occurs irrespective of the type of technology the firms are developing, the size of the firms, or the firm's ownership. In addition, this relationship does not vary according to the type of environmental regulation that is in force. Overall, this dissertation demonstrates that the relationship between environmental regulation and technology development can only be understood with reference to the innovation process that underpins the actions of the technology producers.

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Chapter 1: Background and Rationale

1.0 Introduction

This dissertation examines the role played by environmental regulation as a stimulus for technological innovation in the environmental technology industry. The first goal of this research is, to establish that environmental regulation is an important stimulus for the development of environmental technology. The second is to show that a thorough understanding of the environmental regulation-innovation relationship can only occur if it is placed within the context of the innovation process that occurs at the level of the firm. Through an analysis of the Water and Wastewater Technology industry in the province of Ontario, this research establishes that environmental regulations are an important stimulus for the development of environmental technology, they act indirectly such that their impact is channelled through the compliance requirements of the technology users. The innovation process is found to rely on a close collaborative relationship between the producers of environmental technology and their customers which exists regardless of the type of technology developed or the type of environmental regulation in place.

1.1 Classification of Terms

Before expanding on the goals for this research, it is important to provide a working definition of what is meant by environmental technology. In its broadest sense, Kemp (1993, 1997) defines environmental technology as any "technique, process or product which conserves environmental qualities". These technologies can then be classified as: a) end-of-pipe, b) off-site treatment and remediation technologies, c) process-integrated changes in production technology, and d) environmentally 'friendly' products. In this research however, they are technologies whose purpose is to allow firms that are subject to environmental regulation, to achieve compliance. These can be classified as being of two types end-of-pipe technology, and process integrated technology.

The end-of-pipe technology, which Kemp (1997) also refers to as 'cleaning' technology is designed to remove toxic substances from an industrial firm's wastestream prior to it being discharged into a waterbody, or sewage system. Technologically, these tend to be the more standardized approach to achieving compliance. Examples include carbon filters that can literally be placed on the end of an effluent pipe to remove pollutants, or in the case of the chemical industry the use of activated sludge treatments, in which micro-organisms are used to break down the toxic substances.

The process integrated technologies or 'clean' technologies, on the other hand, are those that prevent the production of toxic substances in the first place, as Kemp (1997) says "Clean technology is preventative whereas cleaning technology is curative". Technologically, this is the more cutting edge or state of the art approach to achieving compliance. Typically, it involves the incorporation of technological systems directly into the firms manufacturing technology. Examples include UV systems, or reverse osmosis technology, or even closed loop recycling systems.

Kemp, in citing Hartje and Lurie (1985) stresses that it is not always easy to classify environmental technologies in this dualistic fashion as overlap can occur. While it is better to think of these technologies as components of a "continuum" of technology options, the dichotomy is convenient and reflects common use among the environmental technology industry.[1]

1.2 Background and Rationale

The aim of this research is to examine the extent to which the production of environmental technology is shaped by the regulatory environment, and to investigate the innovation process that underpins the development of these technologies. The rationale for this research is drawn from a number of quarters. At a broad scale, the research is motivated by current research within economic geography concerning the spatial organization of technological production at the regional scale. Of particular interest here, is the importance of regionally based systems of innovation, within a globalised industrial production system (Cooke and Morgan 1994, Amin and Thrift 1995, Storper 1995, Maskell and Malmberg 1997, Gertler 1998). Couched within this broad research agenda is the role of institutions as drivers of technological change. These institutions, which include physical infrastructure, supplier-user linkages, flows of information, and government rules and regulations, are recognized as playing an important role in regional economic success (Amin and Robbins 1990, North 1992, 1997, Groenewegen, Pitelis, and Sjostrand 1995, Foss 1995, Lane 1997). Of particular importance in this regard is the role played by regulatory institutions. Environmental regulation can therefore, be thought of as part of a regional set of institutional arrangements, which will serve to influence innovation at the level of the environmental technology firm.

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[1] For a list of reported end-of-pipe and process-integrated water and wastewater technologies, please

This research was also motivated by the fact that the Canadian environmental technology industry has been singled out for special mention under various strategic industrial development plans of both the Federal Government and the Government of Ontario (Industry Canada 1994a, MOEE 1994). This status has been achieved in the belief that environmental regulation can be an important catalyst for industrial development, through the creation of new industries dedicated to the development and manufacture of environmental compliance technologies. The Government of Ontario's Green Industry Strategy for example, states "Ontario green industries need to be more involved in and informed about the development of regulations so that they can develop the needed technologies before these regulations are announced" (MOEE 1994, p3). Therefore, the belief is that regional and national governments can create a measure of economic prosperity through environmental regulation. Canada is not alone in this, and may have been influenced by Porter's (1990, 1991) claim about Germany and Sweden (see later). While this proposition has never been tested in the Canadian context, theoretical support can be drawn from a number of sources.

Over the past two decades, some micro-economic studies of policies that attempt to preserve environmental integrity, have focused on the way the policies modify the technical production choices of firms. In the context of technological innovation, they argue that there is a causal relationship between the policy instruments employed by governments and the technological responses of firms (Carraro and Siniscalco 1994, Millman and Prince 1989, Downing and White 1986, Magat 1979,). While these studies and others argue that policy can positively promote technological development, the policy impacts have been exposed

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see Appendix 1.

only through narrow economic models, which treat all firms as being relatively homogenous. They argue that policies force firms to be clean, which creates a demand for technology, and thus technological development occurs. However, these studies focus on the demand side implying that the firm using the technology will also be the innovator. By contrast, the supply side of this relationship –involving those firms manufacturing environmental technology- is weakly developed and at most, it is assumed to 'fall into line' with the increase in demand. Millman and Prince (1989) in theoretical terms explore incentives for firms to develop innovations to control pollution but, much of their discussion centers on different policy instruments affecting firms within a regulated industry, and only briefly do they consider technologies being acquired from outside suppliers. This literature however, is resolutely theoretical and does not use empirical data to test its policy propositions, and there are few case studies provided. An exception to this theoretical focus lies in the work of Sanchez (1997), Florida (1996), Atlas and Florida (1997), and Florida, Atlas and Cline (1999) who address the innovation process at the level of the individual firm that is subject to the conditions of the regulations. This body of work examines the role of firm size, R&D intensity, and the organizational capabilities of firms to try and understand the environmental regulation-innovation relationship.

The role of the demand side is also central to the arguments and counter-arguments concerning the relationship between environmental regulation and industrial competitiveness. Porter and van der Linde (1995a, 1995b), and Hitchens *et al* (1998) argue that there is a positive relationship, reasoning that through innovation, firms will be able to reduce the costs of complying with the regulations. Palmer, Oates and Portney (1995), Jaffe *et al*, and Jaffe and Palmer (1997) reject this 'revisionist' thesis by arguing that there is no clear evidence to suggest that a positive relationship exists. In many cases, the improvements in competitiveness are due to other factors, for example labour cost differentials, energy and raw material cost changes, and non-environmental R&D expenditure increases, rather than a desire to reduce compliance costs. In the end, Jaffe *et al* (1995) conclude that more evidence is needed on this issue and the real truth is to be found somewhere between the two extremes of improved competitiveness, and reduced competitiveness due to increased compliance costs.

What is common to all of this body of work is that it focuses on the demand side. The firm subject to environmental regulation makes the innovation decisions, and experiences the competitiveness impact. Little or no mention is made of firms who supply environmental technology and the impact of the regulations on their competitiveness.

As a counterpoint to the thrust of this demand-side theoretical approach, Kemp (1993, 1997) argues that suppliers are an important consideration in the environmental regulation-innovation relationship because most innovations are supplied by 'specialized' equipment firms. This observation however, is not examined specifically in his work. In similar fashion Lanjouw and Mody (1996) recognise the relationship between environmental regulation and the supply of environmental technology. However, through the use of international patent data their work traces the diffusion of environmental technology in international markets. No insight is given into the organization of the innovation process among the environmental technology suppliers, who their customers are, and the relationship they have with their customers.

Both the demand side and the supply side are addressed, although not equally, in the work of Ashford (1993, 1994), and Porter (1990, 1991). The standards that are embedded in policies legally oblige firms to respond in a positive manner. Ashford (1993) argues that these regulations will elicit different responses by firms. New patterns of activity will be created both within the industry that is directly regulated, and among some firms outside of that industry, principally the suppliers of compliance technology. New competitive opportunities will be created for the supply of compliance technologies, though as I have argued the character of these technologies varies (see above), and may reflect the nature of the regulation.

Porter (1990, 1991) recognizes the importance of environmental regulation as a catalyst for new industrial development and argues that environmental regulation facilitates the creation of new industries concerned with the development and supply of environmental technologies. In supporting the use of stringent standards to stimulate competitive advantage, Porter argues that in the case of Sweden, rigorous environmental standards have allowed environmental technology suppliers to gain a significant competitive advantage against foreign firms producing in jurisdictions where the policies are not as stringent. Unfortunately, Porter provides little evidence to support this contention. He further argues that US leadership in this sector has declined "As Germany, Sweden, and Denmark have moved ahead of the United States in standards governing a number of as aspects of environmental quality, their firms in these areas are increasingly supplying world markets" (Porter 1990, p648).

Solvell et al (1992) note however, that the competitive advantage that Sweden has enjoyed is beginning to erode. Other countries, especially Germany and Japan, have started to implement more restrictive environmental policies that have driven the process of innovation faster. They argue that Germany is particularly active in the development of strict policies with some industries establishing tougher limits than those mandated in the policy. Moore and Miller (1994) support this assessment arguing that Germany has become the international leader in the provision of a variety of environmental goods and services. The OECD (1992) estimates that Germany exports approximately 40% of the value of production in environmental technology compared to 10% in the case of the US. By contrast, OECD views Canada, despite the existence of an actively growing industry, as a net importer of environmental equipment, principally from the US. In his study of Canadian competitiveness, however, Porter (1991) concludes that Canada has a mixed record in the use of regulations to help create competitive advantage. In addition he argues that links between Canadian firms and domestic suppliers are weak, in many cases key technological inputs are sourced from abroad.

These two conclusions taken together do not bode well for the Canadian environmental technology industry, yet Porter is not explicit in his treatment of this industry. He recommends that Canada should continue to move towards stringent standards and regulations as "Tough standards for energy efficiency and environmental impact trigger innovations in products and processes that are highly valued elsewhere" (Porter 1990, p95). Stanbury (1993), however, drawing on the work of Doering et al (1992) and McFetridge (1992), vigorously disputes Porter's recommendations, describing the theory as flawed. Their counter-arguments focus however, on the actions of the regulated industries. They give no consideration to domestic technology suppliers.

The main problem with all the studies I have reviewed is that they do not provide any analysis of the process through which innovation occurs. Kemp (1993) explains that this is a serious problem because the technological strategies of suppliers and users of environmental technologies may differ. Miles and Green (1994) argue further that there needs to be more theoretical and empirical work conducted on the innovative strategies of firms in response to environmental pressures. In particular, they are concerned about how R&D strategies are organized because this influences the technological responses by firms. Firms vary in their capabilities to develop technologies. In the Canadian context, being alert to this variation is particularly important because over 45% of the assets of manufacturing firms are foreign controlled (Porter 1991). In these circumstances the innovation responses to environmental regulation by indigenous and foreign controlled firms may differ.

Neither Porter nor his critics provide an explicit examination of the way that Canadian environmental technology suppliers generate an environmental regulation-innovation link. While a general connection is hypothesized between environmental regulation and innovation, there are no comprehensive empirical data, and this hinders any rigorous testing of the proposition. My research fills this void using selected information collected for Ontario. I analyse the innovation strategies of technology producers, and I address both provincial and federal regulations as I explain the spectrum of technological responses by firms based on the regulatory influence.

While the role of government regulation is the principal institutional structure that I investigate, my research also explores the extent of links between suppliers of technology and their customers that are an integral part of the process of innovation. Fouillard (1992) suggests that there are poor links in Canada between the producers of environmental services and technologies and their users, and that hinders the competitiveness of the environmental technology industry. However, no data are presented to support this argument, nor is there any definition offered of the 'type' of links the author is referring to, especially as services and manufacturing are considered in the same statement. In addition, because Fouillard's statement refers to Canada as a whole, the regional aspects of inter-firm linkages are not understood.

The strong linkages between the environmental technology industry and many of the large resource processing industries have been a feature of successful environmental technology development in Sweden. Solvell et al (1992) argue that the success of ABB Flakt, one of the most successful suppliers of environmental technology, was primarily due to their links to the Swedish processing industry, which provided a testing environment for their technology. In the case of Canadian resource industries however, domestic technology suppliers do not enjoy the same co-operative links with users as their Scandinavian counterparts. Hayter (1988, 1996) argues that little or no systematic co-operation exists between forest-product firms and their equipment suppliers in the development of technology, in Canada. McFetridge (1993) in a review of the Canadian national innovation system observes that in many industries links can be observed between domestic suppliers and users of technology, however, they are far outnumbered by links with foreign technology suppliers.

Gertler (1993, 1994), comments that the manufacturing success of many countries has occurred in conjunction with the development of successful domestic technology suppliers. However, in the case of Canada and especially Ontario, the emergence of competitive indigenous technology manufacturers has not occurred. Instead, manufacturing firms that use advanced technologies are heavily dependent on imports. Britton and Gilmour (1978) note that the development of strong backward linkages with domestic technology suppliers is impeded by the large presence of foreign branch plants who traditionally source their technological requirements from parent firms or suppliers located outside of the country of operation. Therefore, there appears to be a structural weakness in the relationship between technology suppliers and users in Canada. However, no empirical or case study evidence appears to exist concerning the supplier-user relationship with respect to environmental technology, nor has there been an investigation of the regional circumstances.

Overall, existing models of the environmental regulation-innovation relationship have proved to be too general in their approach, lacking an understanding of the complexity of the relationship that occurs between the policy, the technology developer, and the user of the technology. This is strange given that the development of these models has occurred concurrently with the evolution of innovation research. However, there is no evidence of these two sets of research ideas intersecting to provide a more complete understanding of the environmental regulation-innovation relationship. In addition, empirical support for these existing approaches has been drawn from anecdotal sources rather than more robust survey data. As an advancement on these existing models, this thesis proposes a model which acknowledges the importance of a complex innovation process within which the relationship between the policy, the technology developer and the technology user occurs. Support for the new model is generated through an examination of the following research questions:

- What is the link between environmental regulation and the supply of environmental technology in Ontario?
- How is the process of innovation organized in the Ontario environmental technology industry? In particular, what is the nature of the relationship between the environmental technology suppliers and the regulated industries?

1.3 Structure of the Environmental Technology Industry

The environmental protection industry, much less that portion of it manufacturing environmental technology, is a notoriously difficult to industry to define explicitly. The principal reason is many of the activities carried out by this industry are more easily classified under existing industrial codes (Standard Industrial Classification). This hinders the availability of comprehensive data on its activities. The OECD has provided a working definition of the industry: "firms which produce pollution abatement equipment and a range of goods and services for environmental protection and management" (OECD 1992, p5). Many other definitions exist, though they all appear to use the OECD definition as a base (Fouillard 1992, Industry Canada 1994a, Winfield and Rabatnek 1995).

The majority of firms in this industry (approx. 75%) are concerned with the production of environmental technology and services associated with the use of this technology (OECD 1992)[2]. The remaining 25% of firms provide management or consulting engineering functions not related to the development and subsequent use of environmental technology (Figure 1.1). The technologies are characterized according to the environmental problem they are designed to correct. Water and wastewater effluent treatment constitutes the largest share of production (30%), however, this figure includes municipal water treatment and thus, may overstate production for industrial use.

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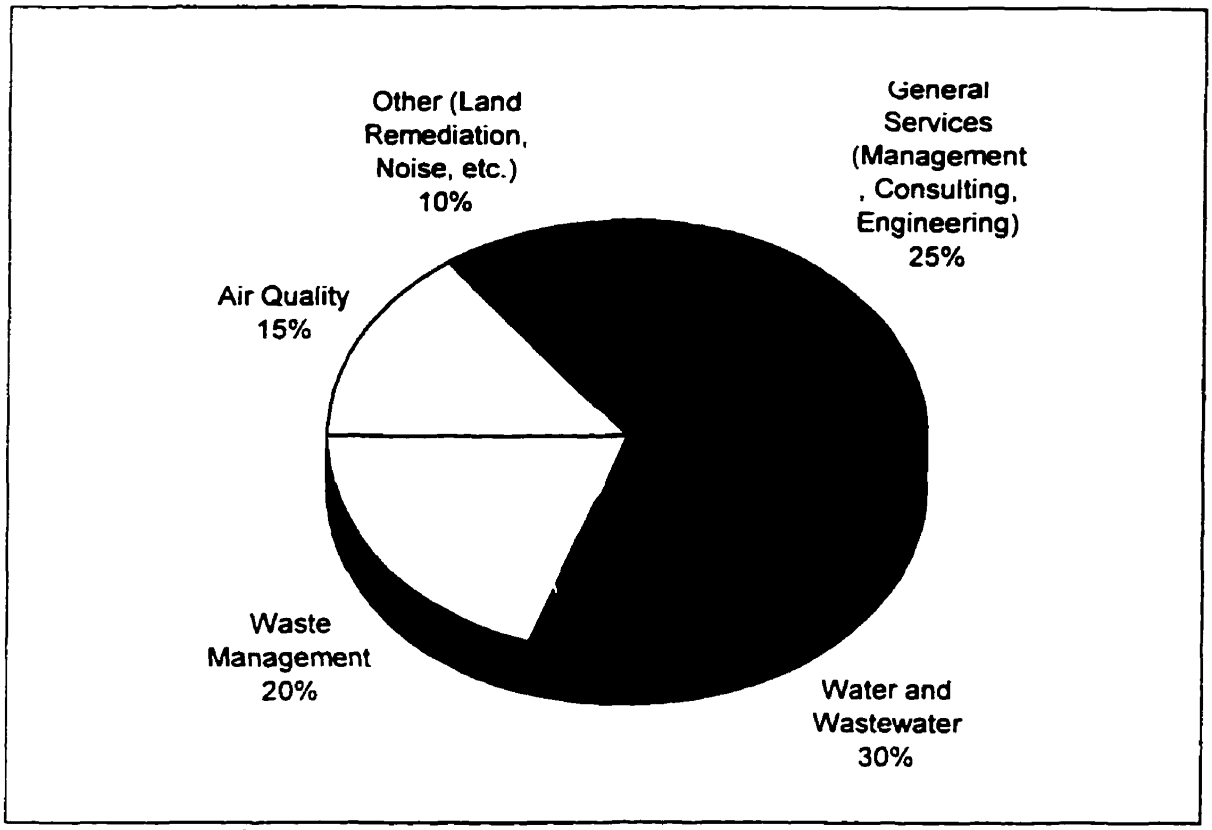
[2] The OECD uses the term 'environmental equipment' rather than environmental technology and reserves 'environmental technology' for 'clean technology'. This is rather a narrow use of the term. It fails to capture the fact that end-of-pipe or cleaning technology can be just as technologically advanced or leading edge as the clean technology.

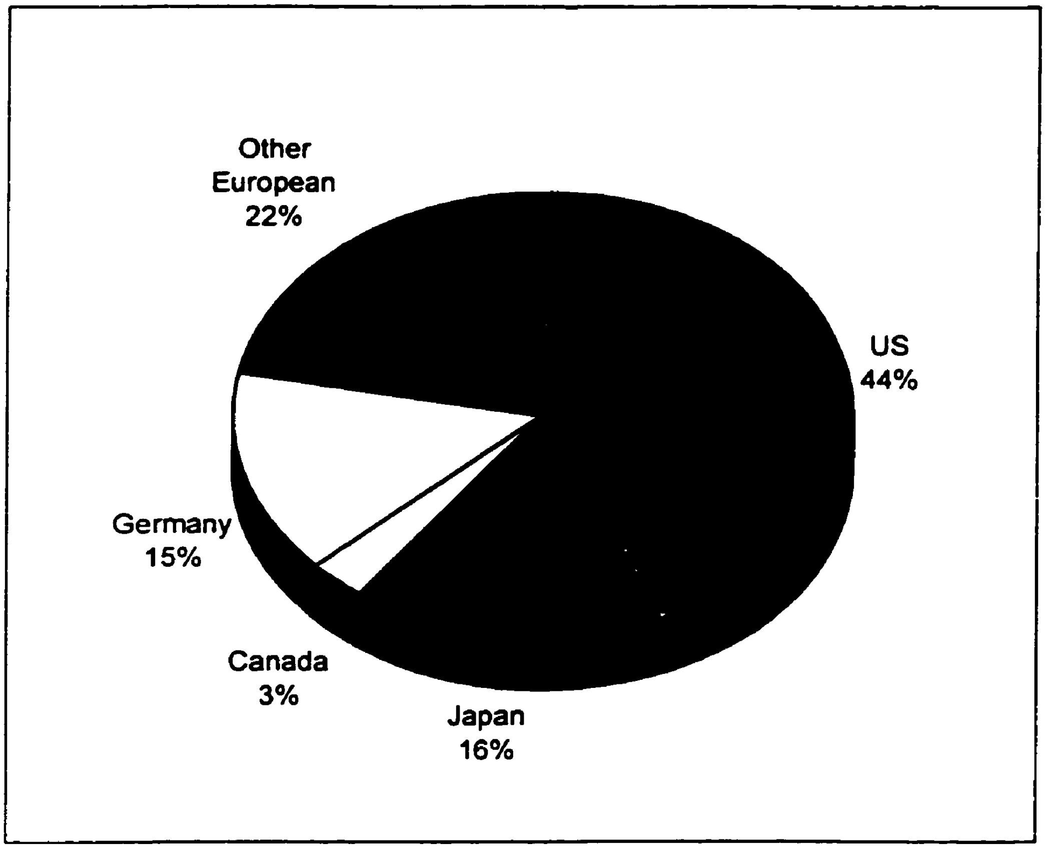
Figure 1.1: Main Components of the Environment Industry, for all OECD Countries



Source: OECD 1992

The national differences in the output, defined by value, of environmental technology manufacturing and service firms are illustrated in Figure 1.2. The US has the largest share of world output (44%), followed by Japan (16%), and Germany (15%) (OECD 1992, Moore and Miller 1994). While the US may hold the largest share of the world output, it does not do so for all technologies, reflecting variations in national environmental concerns and environmental policies. Europe, for example, holds a larger share of the production of water treatment technologies while waste management technology production is higher in the US, and air quality technology production is higher in Japan (OECD 1992).

Figure 1.2: OECD Environment Industry Share of Output by Country



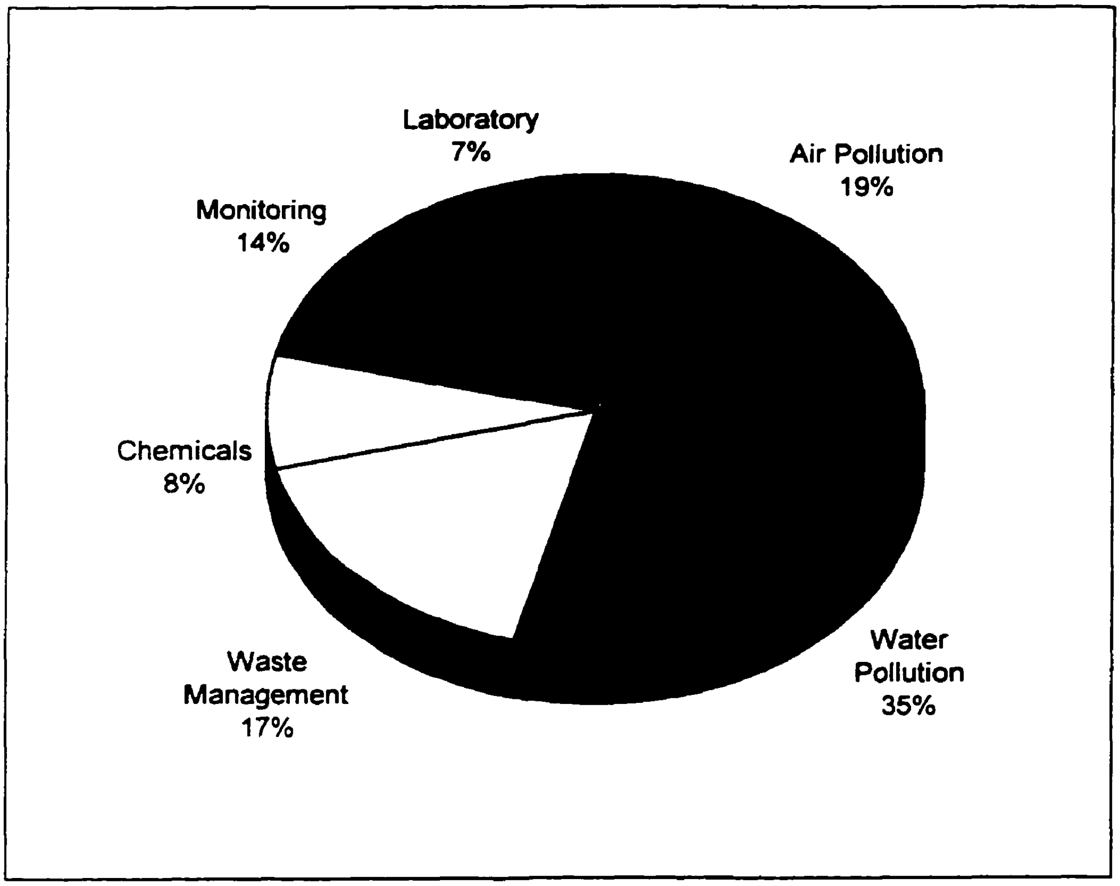
Source: OECD 1992.

The lack of a formal definition of the environmental technology industry in Canada also hinders the collection of comprehensive data on its activities. The best description of its organization however, can be obtained from a variety of reports from government and private consultants (Doyle 1992, Ernst and Young 1992, Doyletech 1994, Industry Canada 1994a, Environment Canada 1997). Based on these sources, the Canadian environmental protection industry is said to consist of approximately 4500 firms employing 150,000 people. Annually, this sector generates about $11 billion in sales. Industry Canada (1994a) estimates that services constitute 60% of the industry with $5 billion in annual sales, while manufacturing embodies the remainder with annual sales of $6 billion. The majority of firms in the industry are small and medium sized firms (SME's), yet it is the small number of large, established, branch plants of foreign multinationals which dominate the activities of this industry in Canada (Industry Canada 1994a).

The industry is concentrated in Southern Ontario with approximately 2000 firms located there, producing 50% of the output of the Canadian industry (Industry Canada 1994a, Ernst and Young 1992, CEIA 1995). Ontario firms are active in a number of markets, for example, air pollution control, water pollution control, waste management, chemicals, instrumentation, and research and laboratory services. Like the Canadian industry as a whole, 60% of output for the sector is derived from services while products account for 20%. One third of all firms are active in more than one market and 25% of firms supply both products and services (Ernst and Young 1992, Doyletech Corp. 1994, Environment Canada 1997).

Employing about 30,000 people, the industry accounts for approximately 3% of manufacturing employment in Ontario (OECD 1992, Statistics Canada 1995, Environment Canada 1997). The firms export 23% of their output (by value), and 30% of the technological requirements for the province is imported (Environment Canada 1997). Viewed in this way, the industry is small, about the same size as each of the Plastics, Paper, and Machinery sectors, but this is typical as internationally, the environmental technology industry accounts for approximately 4% of manufacturing employment in both the US and Germany (OECD 1992). It is, however, an industry with emerging political significance, and an area of new technology development.

Figure 1.3: Structure of the Ontario Environmental Technology Industry, by Product



Source: Industry Canada 1994a, MOE 1992

The majority of environmental technology manufacturing firms produce technologies for the control of water pollution (Figure 1.3), followed by air pollution control and waste management.[3] The majority of suppliers of environmental technology (75%) are small domestically owned firms, averaging less than 25 employees. They generate approximately 13% of the total output for the province ($2.2 billion in 1994) (Environment Canada 1997).

[3] The Water and Wastewater Technology (WWT) subsector was chosen as the industrial focus for this research as it represents the largest subsector of the broader Environmental Technology Industry, not only provincially, in Ontario, but nationally too.

Many of these firms are competitive in niche markets, investing an average of 11-12% of their annual sales in R&D. This figure varies between 8% for multi sector firms, through 9.5% for air pollution control firms, to 21% for waste management firms (Ernst and Young 1992). The remaining 87% of output is generated by larger firms, the majority of which are the Canadian branch plants of multinationals from the US, and Europe. They conduct little R&D in the province and production is generally focused on manufacturing and sub assembly for the Canadian market.

1.4 Structure of the Dissertation

My purpose in this research has been to examine the relationship between environmental regulation and the development of compliance technology by environmental technology firms. Through the lens of Ontario's Water and Wastewater technology sub-sector, the impact of both Federal and Provincial water pollution regulations on innovative activity in these firms is examined.

As a background to the water pollution regulations that are in operation in Ontario, Chapter 2 provides the theoretical basis for environmental regulation. The chapter begins with a discussion of the theorized basis for policy that can induce firms to take responsible actions. I review the various approaches used by governments to restore environmental quality: these include standards, economic instruments, and voluntary initiatives. The application of water pollution legislation in Ontario is then discussed and both federal and provincial approaches are incorporated. A brief international comparison is made at the end of the chapter.

In Chapter 3, I analyse of the theoretical basis for exploring the environmental regulation-innovation relationship in Ontario. I discuss what approaches have been used in the past and the problems associated with them. Of particular importance in this regard are the contributions made by Michael Porter (1990, 1991), and Nicholas Ashford (1993, 1994), who model technological responses to environmental regulation. However, both contributions are general models without any degree of specificity about the process of innovation that occurs at the level of the firm. Neither author makes reference to the substantial innovation literature that had evolved prior to the development of these models. As an alternative to these existing approaches, a model is proposed. While some elements attributable to Porter and Ashford are incorporated it is based on innovation theory and proposes a re-conceptualization of the environmental-innovation process that is more specific than before.

The research methodology used in this enquiry is discussed in Chapter 4. The primary research instrument employed in this study was a mail-out survey to suppliers of water and wastewater technology. The data generated from this survey were supported with a series of 'follow-up' interviews with technology suppliers, their customers and representatives from government. In addition to describing the research methodology, this chapter also provides data on some key structural characteristics of the water and wastewater technology sub-sector.

Chapters 5 and 6 provide an empirical validation of the conceptual model proposed in Chapter 3. Using the data received from the mail-out survey and supported by interviews, the role that environmental regulation plays as a stimulus for innovation in the water and wastewater technology sub-sector is tested in Chapter 5. Empirical support is provided for conceptualization of the environmental regulation-innovation relationship. The chapter also examines, in detail, the path through which the regulatory stimulus may flow in the conceptual model. The supply-side relationship is explained and the importance of technology supplier firms is verified.

Building on the conclusions of Chapter 5, the purpose of Chapter 6 is to explore in greater detail the nature of the innovation process underlying the development of water and wastewater technology in Ontario. Accordingly, the focus of the chapter is the relationship between the technology suppliers and their customers. In short, it indicates that an interactive innovation process occurs in the development of water and wastewater technology in Ontario.

Chapter 7 presents a summary of the principal findings and conclusions of the dissertation. This has three components. First, the main findings of the research are summarized and interpreted in the context of the objectives of the enquiry. The relationship between environmental regulation and innovation, as it applies to the Ontario Water and Wastewater Technology sub-sector, is reviewed. In addition, the organization of the innovation process underlying the development of water and wastewater technology is re-examined. Secondly, the chapter speculates about the application of the environmental-innovation model to other sub-sectors of the environmental technology industry, and the validity of this model under different regulatory approaches. Finally, the chapter concludes with a discussion of the future directions along which this research could proceed.

Chapter 2: The Theory and Application of Environmental Policy

2.0 Introduction

As the primary goal of this thesis is to examine the role that environmental policy plays on the innovative behavior of environmental technology firms, it is necessary to examine the theory that underpins the operation of environmental policy. The chapter also illustrates how these policies are applied in practice, focusing specifically on the application of water pollution control legislation in Ontario. A brief international comparison will be made at the end of the chapter.

2.1 The Theory of Environmental Policy

The primary objective of pollution control is to reach some optimal or desired standard of environmental quality. This can be achieved in two ways, either by increasing the absorptive capacity of the environment, or by reducing the quantity of waste produced as by-products of economic activity. Economic theory suggests that a balance be maintained between environmental resources as media for the absorption of wastes and their use as amenity resources (Pearce and Turner 1990, Rees 1990). This approach has sought not to prohibit the discharge of pollutants, but rather, to establish an optimal level of pollution where the benefits of pollution control are equal to the costs of elimination.

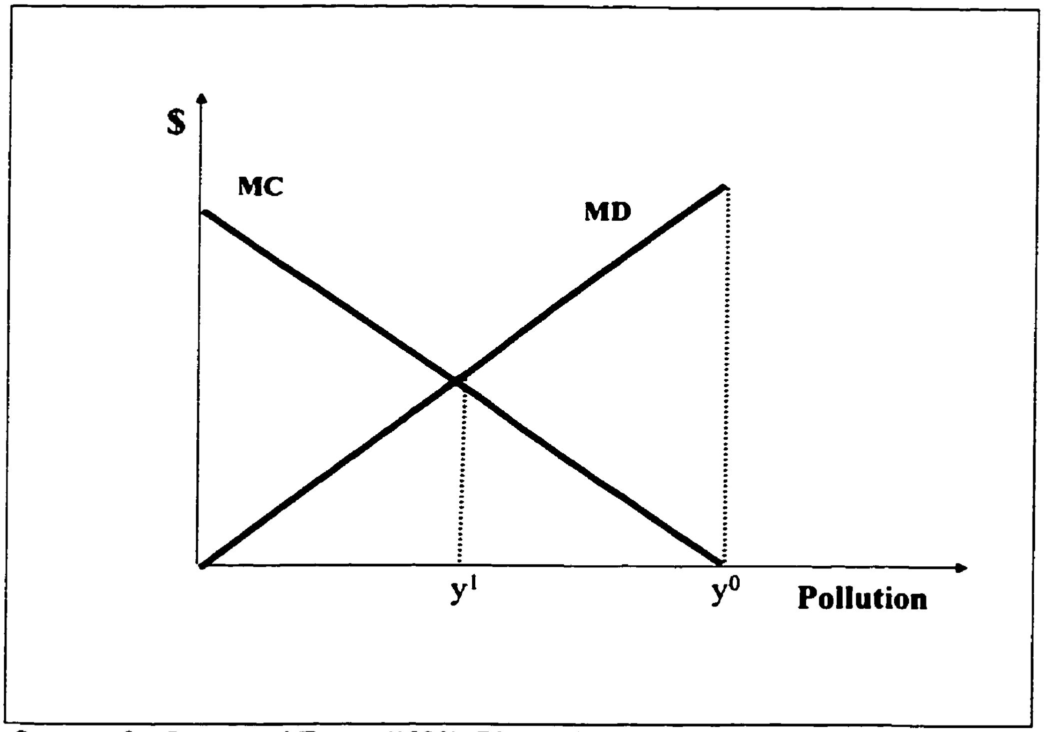
2.1.1 The Socially Optimal Level of Pollution

Neo-classical economic theory postulates that the market mechanism will guarantee the allocative efficiency of scarce resources among competing users. However, no market exists for either pollution or environmental quality. The environment is a common property resource, meaning that its use is shared with others (Pearce and Turner 1990). As a result, an industrial firm may discharge the waste material of its production process into a river or lake without having to pay for the damage caused to the local community in which that firm is located, or the downstream users of the waterbody.

The damage costs imposed on the local community by the actions of the firm are called 'social costs' as they reflect the loss of welfare experienced by the community as a result of the production decisions of the firm. These social costs are external to the firm's private costs, and are not included in the costs of production for the firm. Consequently, they can be referred to as an externality that the economic literature defines as occurring when part of the cost of producing a good is paid for by a firm, community or individual(s) other than the one that produces it (Anderson and Leal 1991, Pearce and Turner 1990). As a result of these externalities, the market as a mechanism for the allocation of resources, is said to 'fail', and profit maximizing firms which pollute are thus responding to an imperfect economic market which fails to provide a socially optimal allocation of environmental resources. Under this condition, environmental degradation occurs.

The existence of externalities suggests that some form of corrective mechanism is necessary to restore pollution levels to a more socially desirable level. The socially optimal level of pollution occurs at the at the point where the marginal costs of control to the firm are equal to the marginal costs of further damage to the community (Dewees et al 1975, Pearce and Turner 1990, Dietz and van der Straaten 1997).

Figure 2.1: The Firm and the Socially Optimal Level of Pollution



Source: after Pearce and Turner (1990), Dietz and van der Straaten (1997)

Figure 2.1 illustrates this relationship graphically. The Marginal Cost curve (MC) represents the costs of pollution reduction by the firm. It is a downward sloping curve reflecting the lower cost to the firm of low levels of pollution reduction. The Marginal Damage curve (MD) represents the costs imposed on the community as a result of the firm's manufacturing activity. It is positively sloped reflecting the fact that each additional unit of pollution imposes a greater cost on society. If no reduction in pollution occurs, the firm will minimize its costs at point y^0. At this point, MD > MC, indicating that the damage to society due to pollution, is greater than the costs of reducing that pollution for the firm. Society would benefit if the firm reduced its levels of pollution to the point where the marginal costs of pollution reduction for the firm are equal to the marginal damage imposed on society. This socially optimal level of pollution occurs at point y^1, and will be achieved by motivating firms to internalize the 'unaccounted for' costs of production.

The existence of externalities suggests that some form of corrective mechanism is necessary to restore pollution levels to a more socially desirable level. Hahn (1989) and Baumol and Oates (1990), suggest that this corrective mechanism should be in the form of government intervention through the imposition of Pigouvian taxes,[1] tradable permits, or the direct regulation of the polluting firm. Coase (1960, 1988) is sceptical about the role of government, arguing that the mere existence of an externality is not sufficient grounds for government intervention. He argues that a natural tendency exists for a socially optimal solution to occur regardless of who holds the property rights in the use of a resource. This will occur through a negotiation process between the firm and the community affected by the firm's actions. If the community has the right to a clean river or lake, the firm will compensate the community for the loss of welfare as a result of production. Alternatively, if the firm holds the property rights to use the river or lake as a waste sink, then in order to achieve a socially optimal level of pollution, the community must, in theory, compensate the firm for its lost production. In both cases, the firm has an incentive to maximize its utility from production, and the community has an incentive to minimize damage. The same socially optimal result will occur whether the government restricts pollution or allows it without restriction.

Central to Coase's argument is that the access to, and quality of, information is the same for the firm and the community. This is captured under the concept of transactions costs, which includes the costs of bringing the parties together, the costs of identifying the sufferers and the ownership of property rights, the costs of valuing a particular resource, and the cost of the bargain itself. The condition of zero transactions costs will allow private and social costs to be equal (Coase 1988, 1992, Williamson and Winter 1991). Pitelis (1993) also considers the role of that transactions costs play in market failure arguing that market failure is essentially due to the lack of information. If the costs of carrying out the transaction, in this case the bargaining for a socially optimal level of pollution, exceed the benefits the compensated party would receive, it would not be efficient to bargain. In this situation, it would be necessary for government to intervene to achieve a socially optimal condition. Government intervention achieves this optimal standard of environmental quality through what economists call a 'second-best' solution (Blackorby 1990). Second-best solutions arise when, through market imperfections, the actions of one group in society decrease the welfare of another group. Government thus intervenes to restore a second best allocation of resources.

2.1.2 Policy Instruments

While society generally accepts the intervention by government, the form that this intervention takes is not universal in agreement. There are two principal approaches used. The first is direct intervention through the setting of pollution control standards. This represents the traditional approach used by government. The second, a more indirect approach, is the use of economic instruments in the form of pollution taxes and tradable emission permits. In addition to these interventionist approaches to restoring a socially optimal level of pollution, a third, less interventionist, method has begun to emerge. This involves the firms regulating themselves through voluntary initiatives.

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[1] So named after the economist A.C. Pigou. They are also referred to as effluent or emissions taxes.

Standards

The standards approach to environmental policy is an example of a command mechanism used by policy makers to achieve compliance with stated policy objectives (Tuohy 1989). It is the dominant regulatory instrument for the maintenance of environmental quality (MacDonald 1991, Hahn 1989, Dewees 1983).

The regulatory agency sets the maximum level of effluent acceptable, and using one of two approaches, decides the best method of compliance. The two approaches are a performance standard and a technology or design standard (Laplante 1990, Nichols 1984). Under a performance standard, the firm is free to choose whatever means it deems necessary to reach the designated level of effluent reduction. This allows the firm the flexibility to choose the approach that best fits with its particular production function. The costs of controlling pollution emissions are specific to the individual firm. Each, under a performance standard, will use the most cost effective method possible. Some will re-organize production, some will change their input mix, while others will install technology to reduce the quantity and quality of effluent.

The second type of regulatory standard involves the embodiment of detailed technological specifications. The technology-based standard is most commonly implemented under a format advocating the "best available technology" (BAT) or "best available technology economically achievable" (BATEA) criteria. This approach according to Magat (1979) will, at best, advance the diffusion of existing 'best practice' technology. The rationale for this policy is that firms, once they have achieved compliance through the adherence to the technological requirement have little or no incentive to innovate beyond this level. The development of a more effective control technology could result in the regulatory agency requiring that all firms adopt it. This would increase the costs of compliance to the firm. Therefore, little incentive exists to encourage the discovery of new technology.

Economic Instruments

Alternative mechanisms for environmental regulation exist in the form of economic instruments. The justification for using the market for eliminating industrial pollution is that environmental problems are a consequence of market failure. They are, in other words, external to the normal market system of supply and demand, consequently the market cannot deal with this situation in the normal course of its operation. Tussing (1990) argues that market oriented solutions are the most efficient way of dealing with market failure. Economists advocate the market solution to pollution control because of its flexibility. Any given amount of environmental improvement can be achieved at a minimum cost. When individuals have property rights in a resource, they tend to consume it in a less wasteful fashion than a resource held in common (Lipsey 1990). Because of this, a market-based solution has as its goal the forcing of users to recognise the social consequences of their use of a common property resource. This is accomplished by putting a monetary value on the consequences and then applying the costs to the user, which is usually the firm. The two most common forms of economic instruments used by policy makers are effluent charges or Pigovian taxes, and tradable permits.

Effluent charges are prices that are paid by firms for discharging waste products into the environment. The charge is levied on the polluting firm by government usually in the form of a tax. It is most commonly charged on the total quantity of waste discharged rather than on its concentration, in other words, on a per-unit of pollution emitted basis. In order to ensure a socially optimal reduction in the levels of discharge, the tax is set at a rate that will induce firms to control effluent, until the marginal cost of abatement is equal to the discharge.

Tradable or marketable permits, which have received much interest in recent years, are in reality the least used policy instrument for controlling pollution (Hahn 1989, Tietenberg 1996). With this approach, the government sets a maximum desired level of pollution. Firms are allocated permits, allowing them to pollute up to a specified level, based on their effluent history. The firms then trade these permits, the quantity traded being dependent on the firms' ability to reduce pollution. Firms who have the lowest abatement costs will sell their permits to those firms whose abatement costs are higher. For the system to work effectively, permits must be allowed to be traded freely (McFetridge 1990).

There are four components of emissions trading, netting, bubbles, offsets and banking (Hahn 1989). **Netting** allows a firm to create new emissions in one plant provided they are offset by reductions elsewhere in the same plant. In this way, the plant's net emissions do not increase beyond the level specified in the permit. **Offsets** are similar to netting in that they allow new emissions to take place. However, these new emissions cannot exceed the ambient standard. They *must be offset* by reductions either in the same plant or other plants in the same area. These offsets are obtained either by internal trading within the same plant or by external trading with other plants in the same area. A **Bubble** refers to all sources of the controlled pollutant in a particular plant, combined. It allows plants to add the emission limits from all sources and to adjust the control limits on these individual sources, within the total limit or bubble. As a result, emissions reductions will occur in the most cost-effective locations. **Banking** is the situation where the plant can accumulate emission permits beyond the required level, to be used or sold in the future.

Voluntary Initiatives

The use of voluntary initiatives as a method of effluent reduction by firms is beginning to be recognised as an important trend in industrial environmental strategy. Fischer and Schot (1993) contend that the trend of "institutionalisation of environmental concerns within firms" will continue. The approach is essentially a strategy of self-regulation by firms, involving pollution reduction, monitoring and internal policy and practice, initiatives.

Schmidheiny (1992) provides a list of a range of inducements for firms to engage in a process of voluntary initiatives. This list includes the threat of stringent regulatory policy on the part of government, the requirement that firms provide evidence of their environmental performance, public pressures either directly or indirectly through consumer decisions, and pressure from other firms who adopt more progressive attitudes to environmental concerns. Williams, Medhurst, and Drew (1993) in an examination of the environmental attitudes of 117 firms in the UK, provide a similar classification of influences again ranging from more stringent environmental policies to community and commercial pressures. They conclude though, "The two main driving forces have been fear of developing a bad image and government regulation". The degree to which the firms have responded to these pressures is positively correlated with the strength of the pressure. In other words, those firms who experienced the greatest pressure also responded to a greater degree in terms of a stronger overall corporate strategy. MacLaren and Labatt (1998) echo this conclusion in their characterization of voluntary initiatives in effect in North America.

Steger (1993) also suggests that firms react in a variety of ways according to the type of pressure they are exposed to. He proposes a taxonomy of strategic responses:

Indifference occurs in firms that are perceived to have a low environmental risk and a low potential for environmentally-related market opportunities. These firms would not benefit strategically from an environmentally progressive stance though Steger suggests that the firm may implement environmentally beneficial practices such as using recycled paper or adopting energy-saving measures.

Offensive strategies generally occur in firms who perceive the environment as an opportunity for market growth, particularly in markets for pollution control and monitoring technology. This strategy would also include the development of environmentally responsible products.

Defensive responses are carried out by firms that are considered to represent a strong environmental risk, for example, the organic chemical industry. These firms also have little opportunity for developing markets in environmentally benign products and processes. These firms are more likely to adopt existing pollution control technologies.

Innovative strategies are those associated with firms who pose the greatest threat to environmental integrity. As a result they come under the greatest pressure from government and the public. These firms also see the potential in developing markets for radical innovations in the form of new products and processes with no environmental impact.

Schmidheiny (1992) argues that the adoption of voluntary strategies may be not only a lower cost method of compliance for firms, but for society as a whole. The rationale for this is firms are usually better informed about the emissions and the methods and technologies necessary for the reduction of these emissions. Therefore government can avoid the cost of gathering the necessary information needed to regulate effectively. The process of monitoring would, in addition, be less adversarial than either standards or economic instruments.

While voluntary initiatives appear to represent a lower cost and more effective method of achieving environmental protection, it still requires the initial pressure from government policy in the form of standards or economic instruments. Fisher and Schot (1993) argue that "On the average, firms do not develop their own policies, but react to outside regulatory, public, and, to an increasing extent, market pressures". Therefore voluntary initiatives may be a more long-term strategy for firms after the initial compliance with a particular regulatory regime, or in combination with a regulatory policy.

One application of a voluntary initiative lies in the ISO 14000 series of environmental management standards from the International Organization for Standardization (Dowdeswell and Charnovitz 1997, Bergeron 1997). In order to receive certification, firms are required to develop and implement a set of policies and procedures known as an environmental management system (EMS). This EMS, which is the cornerstone of ISO 14000, allows the firm to set its own goals and objectives for environmental performance, in addition to developing a plan for achieving them. Therefore, the ISO does not state a minimum set of environmental 'standards' that must be achieved. Instead, in order to achieve certification, the EMS must be in place, and must be reviewed periodically for improvement (Bergeron 1997).

2.2. The Application of Environmental Policy in Ontario

In Canada the standards approach is the dominant policy instrument (MacDonald 1991, Conway 1990). The reduction in air pollutants, Dewees (1991) argues, is due to the standards approach applied at all levels, federal, state, and local. He further argues that the reduction in water pollution, while not as marked as the reduction in air pollution, is nonetheless directly attributable to pollution control standards. In particular the reduction of phosphorous, DDT and mercury in the Great Lakes is of note.

Pollution is regulated in Ontario through all three levels of government, Federal, Provincial and Municipal, in the form of regulations, guidelines and by-laws. The Federal government, through Environment Canada, sets standards and guidelines for a number of pollution media principally under the direction of the Canadian Environmental Protection Act (CEPA) and additionally in the case of water pollution, the Fisheries Act. An example of such a regulation under the Fisheries Act are the Pulp and Paper Regulations, which place limits on a variety of toxic substances contained in the effluent of pulp and paper plants. Other sectors targeted under the Fisheries Act include meat and poultry plants, metal mining operations, and chlor-alkali plants. Despite the fact that the Fisheries Act is probably the most powerful weapon of the federal government, the responsibility for the environmental protection of waterbodies is left largely with the provinces (MacDonald 1991, Estrin and Swaigen 1993).

2.2.1 The 'Approvals' Process

Ontario's regulations are set under the province's Environmental Protection Act, and in the case of water pollution the Ontario Water Resources Act (OWRA). The OWRA, which is the principal instrument used to control water pollution, does not set explicit limits for particular substances. Instead it is framed in terms of a general prohibition against the discharge of pollutants into water. The quality of the receiving water will be considered impaired if damage to fish, or other wildlife occurs. What actually constitutes the impairment of a waterbody, is determined largely through a set of guidelines contained in the Ministry of the Environment publication 'Water Management: Goals, Policies, Objectives and Implementation Procedures of the Ministry of the Environment'. This is known, less formally, as the 'Blue Book Guidelines', so named because of the color of the publication's cover (Estrin and Swaigen 1993).[2] In addition to guidelines regarding the quality of water for consumptive purposes, the Blue Book guidelines contain water quality objectives for other purposes including recreation, agriculture in the form of water for irrigation and watering livestock, and guidelines for concentrations of pollutants in effluent discharged from sewage treatment plants and industries. These guidelines, which cover such conditions as temperature, turbidity, pH, and concentrations of certain substances including oil, cadmium, pesticides, and lead, refer to the quality of the *ambient* water. That is, they refer to the concentrations of these substances or the presence of these conditions on the quality of the *surrounding* water at any particular point in time. No one source of impairment is considered. Rather, the guideline considers the impact of combined sources of contaminants on the quality of the water. This is the opposite of a 'point-source' approach, which would specify the maximum concentration of a contaminant that an individual or point source could emit.

The water quality guidelines are not enforceable in their own right, because they are simply a statement of desired objectives for water quality. However, where they do become enforceable is when they are incorporated into a system of licenses, known as the 'Approvals Process' (MacDonald 1991). This licensing system is the method through which the OWRA is applied in practice and consists of Certificates of Approval and Control Orders. The Certificate of Approval, which is the same thing as a license, and is required by all firms in order to operate. The contents of the certificate are determined essentially through a bargaining process between the firm to be regulated and the regulating authority. A firm wishing to operate in a particular location, or wishing to expand its existing facility will apply

[2] The use of the term 'Blue Book' also allows this publication to be distinguished from the 'Green Book' which are the 'Ontario Drinking Water Objectives'.

to the ministry outlining the nature of its production process and specifying the type of environmental technology that will be used. The ministry will examine this proposal and attempt to predict the pollution effects of this activity. If the environmental effects of the proposed activity fall within the water quality guidelines, the certificate is approved. Consequently, the certificates are approved on a case-by-case basis. Once in operation, if the firm exceeds the water quality guidelines, the ministry will issue a Control Order. This order sets out a legally binding program of effluent reduction that must be followed by the firm. Typically, the control order will require the installation of specified environmental technology, usually end-of-pipe technology. For example, a chemical firm may be required to install a secondary or even a tertiary treatment of their effluent before the ministry will allow production to continue.[3] This approach to environmental regulation can best be described as an example of a technology-based standard.[4] The reasoning is that the license will be approved largely on the basis of the environmental technology the firm is proposing to install. In fact, a firm is prevented from upgrading its production facilities, including its pollution control measures, without the express approval of the Ministry. In addition, the Control Orders will mandate the installation of specific technologies for compliance.

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[3] For many chemical firms, pollution is controlled in three stages referred to as Primary, Secondary and Tertiary treatments. Primary treatments are used to remove solids from the wastestream. They include Neutralization, Clarification, Chemical Precipitation, and Flotation. Secondary treatments are used to remove dissolved carbonaceous pollutants, through biological processes. The principal secondary treatment in use is Activated Sludge Treatment. Tertiary treatments are employed when the effluent from the Secondary treatment is inadequate. The most common process is Granular Media Filtration.

[4] This interpretation of the OWRA is consistent with that of the Ministry of the Environment, verified through interviews with both the Policy Development, and Science and Technology

2.2.2 Municipal Industrial Strategy for Abatement

An alternative to this approach is the performance-based standard, which is found in the Municipal Industrial Strategy for Abatement (MISA). The Ministry of the Environment introduced this initiative in 1986 because the existing approvals process under the OWRA was not working effectively. The problem was due to a number of inconsistencies in the contents of the Certificates of Approval and the Control Orders (Mausberg 1990, Estrin and Swaigen 1993). In addition, in 1985, a particularly toxic discharge of perchloroethane by some prominent chemical companies, was made into the St. Clair River, effectively forcing the establishment of the MISA.[5] This prompted the Minister of the Environment at the time, Mr. Jim Bradley, on launching the programme to state that " the system was up-to-date a decade ago, but it is inadequate now..." (MoE 1986).

MISA targets over 300 establishments contained in nine industrial sectors (see Table 2a, Appendix 2 for a list of these sectors). These establishments are deemed to be direct dischargers, meaning they discharge their liquid effluent directly into a waterbody. The program also addresses a number of establishments who are deemed to be indirect dischargers meaning they discharge effluent into the municipal sewer system. However, these indirect dischargers are not targeted by sector as in the case of the direct dischargers. There were two stages to the full implementation of MISA. The first was the monitoring of toxic substances for each industrial sector targeted, in order to build a database of toxic substances and conventional contaminants. This database was then used to determine acceptable levels of effluent both at the firm and sectoral levels. The second stage was the specification of

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branches.

[5] Perchloroethane is a dry cleaning fluid, and approximately 10,000 litres was spilled. The incident became known as the 'Toxic Blob' (Vigod 1990).

limits for contaminant concentrations. These were based on either: (a) loadings that could be achieved by BAT or, (b) the maximum loading levels acceptable to achieve ambient water quality, as determined by the Ministry of the Environment.[6]

All establishments targeted by MISA are required to control the discharge of particular toxic substances within specified limits. So unlike the guidelines contained in the OWRA, under MISA specific effluent standards have been developed. These standards have been determined through what is called the Best Available Technology (BAT) criteria. While this sounds like a technology-based standard, the firms are in fact free to choose whatever means of compliance they see fit according to their particular production function. A performance-based standard will, in effect, set effluent limits for particular toxic substances without actually mandating how they should be followed. The BAT standard the Ontario Ministry uses sets the minimum acceptable limit of a substance that could be achieved if the most advanced technology available was used. In practice, this BAT requirement acts as a type of hybrid between the 'theoretical' design and performance standards. In the US, the Clean Water Act uses the BAT criterion. However, like MISA, no formal definition of BAT exists. The US Environmental Protection Agency (EPA) through practice maintains that the best available technology should be used as long as no plant closures or job losses result from its application. (Salamon et al 1990, Koch and Leone 1979).

The Ministry of the Environment (MOE 1991) has identified environmental compliance technologies that are feasible for each industrial sector. With regard to conforming to the BAT requirement, these technologies were identified according to the

[6] These loadings were calculated by multiplying the concentrations of contaminants by the flowrate of the waterways (MOE 1986).

following criteria: (a) efficiency in removing specific pollutants, (b) capital costs relevant to the type and scale of each abatement technology, (c) operating and maintenance costs, (d) operating life of abatement technologies, (e) private benefits of each BAT option, including reduced energy or materials inputs, saleable by-products, reduced labor requirements, and enhanced production efficiencies.

2.2.3 Municipal By-Laws

In addition to the federal and provincial legislation described above, water pollution is also controlled at the municipal level through a series of by-laws that are expressed under the Municipal Act. This Act facilitates the building and operation of municipal sewer and water systems by municipal councils. Typically, the by-laws concerning water quality will govern the concentration of effluent entering the sewer system. However, since 1988 greater emphasis has been placed on the elimination of pollutant discharge rather than the reduction in pollutant concentration (Estrin and Swaigen 1993).

2.4 International Environmental Policy

In developing his view of the positive relationship between environmental regulation and a competitive environmental technology sector Porter (1991) cites (although briefly) the success of firms in this sector in the United States, Germany and Sweden. Since Canadian regulations are based on international experience and since Ontario's industry contains foreign firms, it is relevant to review water pollution regulations in these international jurisdictions. In general, the regulatory experience in these other countries reflects a combination of approaches from traditional command and control type standards to the use of market based initiatives.

2.4.1 United States

Water pollution is regulated in the United States under the Federal Water Pollution Control Act 1972 (FWPCA).[7] Under this Act, the Federal Environmental Protection Agency (EPA) has established a number of pollutant specific water-quality goals and standards that are applied to different industrial sectors (Vogel 1986, Freeman 1992). This is similar to the industry specific regulations of the Fisheries Act in Canada, or the industrial sectors targeted under Ontario's MISA programme. In addition to the establishment of federal water quality standards, the FWPCA also allows provision for individual states to establish their own standards for instream water quality (*i.e.* suitable for swimming, boating, and fishing). The US State-determined standards, which designate the maximum allowable concentrations of pollutants, are also required to undergo a review process every three years (Rabe 1990, Freeman 1992).

The standards set by the EPA are technology-based mandating the level of technological sophistication necessary for compliance. Quantitative limits are set for particular pollutants with reference to what can be achieved using the 'best available technology '(BAT) or in some cases the 'best practicable control technology' (BPT). The difference between these technological classifications is, as Freeman (1992) notes, ambiguous and open to different interpretations. The method which the EPA uses to enforce these technology-based standards is a system of discharge permits which must be held by all

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[7] This Act was subsequently amended in 1977 under the Clean Water Act and in 1987 under the Water Quality Act 1987. These amendments represented fine-tuning of the original Federal Water Pollution Control Act 1972 (Freeman 1992).

firms. The permit will contain the maximum allowable discharge of pollutants by the firm that are consistent with the use of either the BAT or BPT as the case may be. These permits are also subject to review periodically, in order to maintain a minimum level of water quality.

2.4.2 Sweden

In Sweden, the Swedish Environmental Protection Agency (Naturvardsverket), through the application of the Environmental Protection Act holds the responsibility for protecting water quality (Kronsell 1997). This occurs through the use of pollution standards promoting the 'best practicable' means for compliance, in similar fashion to Ontario's MISA programme (Heidenheimer, Heclo, and Adams 1990).

The standards are administered through a system of permits that are issued on a plant-by-plant basis regulating the total emissions for the particular plant or factory. The rationale for this plant-by-plant approach is that the emissions can be controlled as part of an overall integrated 'package' of pollutant types (air, water, or waste) rather than trying to regulate individual wastestreams (Hinrichsen 1990). As such, this is a 'bottom-up' as opposed to a 'top-down' approach. The permits are required not only for the establishment of a new plant, but also in the case of a change in the plant's production process, or an increase in the plant's capacity through expansion or the introduction of new technology. In each of these cases the plant is required to apply for a new permit.

The responsibility for control and enforcement of the standards lies with either local, regional or national environmental protection authorities. They set the overall standards in consultation with industry and technical experts. At the heart of the permit system is the role of technology. Hinrichsen (1990) states that one of the cornerstones of the Swedish approach is that the permit system is driven by technology. The permits allow the plant to implement the 'best-practicable means' which is defined as the most efficient technologies that are used in similar plants in Sweden or internationally. This includes pollution control and pollution prevention measures. In granting a permit, the Swedish Environmental Protection Agency will take into account the technical feasibility of the proposed compliance measures. At a minimum, these must conform with the 'best practicable' benchmark. The permit granting authorities also monitor the plants quite closely, and as control technologies advance and production processes achieve greater efficiency, the standards are adjusted to take account of this.

2.4.3 Germany

Unlike that of Canada, the United States and Sweden, the German experience in water pollution legislation lies in the combined use of standards and effluent charges rather than standards and permits alone. The standards approach is reflected in the Federal Water Act 1976 (Wasserhaushaltsgesetz), while the use of effluent charges are embodied in the Effluent Charge Law 1976 (Abwasserabgabengesetz) (Brown and Johnson 1986, Hahn 1995). While the federal government holds the responsibility for implementing environmental legislation, the responsibility for enforcement is left largely to the local or Lander governments (Bennet and von Moltke 1990)

Under the Federal Water Act, the German government has established a set of uniform standards for a variety of toxic substances that are discharged by both municipal sewer systems and industry. In the case of industry, the standards vary according to the industry in question. In similar fashion to the United States, the standards incorporate a technological criterion for determining the minimum acceptable level of discharge. Thus, the standard is based on technology that is 'best practicable' or 'commonly accepted' for the particular industry (Brown and Johnson 1986, Wallace 1995). The responsibility for enforcing these standards lies with the Lander governments. This is achieved through the application of permits that are required by all firms. In order to ensure the permits reflect the current state of water quality, they are subject to periodic assessment, and can be revoked if water quality improvements are needed.

Concurrent with the Federal Water Act, the Effluent Charge Law is the second tool used by policymakers to protect water quality. Unlike the Federal Water Act that sets uniform standards to be applied to all firms, the Effluent Charge Law applies only to firms who discharge pollutants directly into receiving waters (Hahn 1995). The Lander governments issue permits to firms who are considered to be direct dischargers. These permits will contain the maximum allowable concentrations of given pollutants and the volume of waster the firm expects to produce over a particular time period. The permit will also contain the rate at which the firm will be charged for this expected waste level. At the very least, firms are expected to maintain a level of wastewater quality that is consistent with the Federal Water Act.

Brown and Johnson (1986) note that there is a financial incentive built into the effluent charge system for the firms to meet the federal minimum standards. If the federal standards are met, the charge per-unit of discharge is cut by 50%. The Lander may also impose water quality standards that are stricter than those set by the federal government (Brown and Johnson 1986, Hahn 1995). In such cases, the firms are expected to meet the Lander requirements before the per-unit charge will be reduced. Overall, firms have an incentive to meet the Federal minimum standards, as not only will they qualify for a reduction in their effluent charge, but they will also avoid federal prosecution.

2.4.4 Summary

In reviewing the policy approaches to preserve water quality adopted by different countries, a number of similarities emerge. The water pollution policy instruments used in these international jurisdictions are summarized in Table 2.1. All have adopted a standards or command and control approach to regulation, although Germany also employs a system of effluent charges. This demonstrates that governments still favour a command and control approach to environmental policy, in spite of a growing interest in market based approaches. In addition, the standards implemented in these international jurisdictions are set with reference to some form of technological criteria, although the application of these criteria seems to vary according to jurisdiction. In the United States and Germany, permits are granted on the basis of the type of technology the firms are using. As long as this is consistent with the particular technological criterion, the permit is granted. In Sweden, the standards are not based on a particular technology, but rather on a package of technological measures that include production technology and pollution control and prevention technology. In Ontario, the MISA programme exists as a hybrid between traditional technology-based and performance-based standards. The BAT criteria is similar to that used in the US, however, firms are given the flexibility to adopt whatever measure they deem appropriate for compliance as long as it meets the minimum standard.

Table 2.1: A Summary of International Water Pollution Regulations

Country/Province	Application	Approach	Technology[8]	Review Process
United States	Federal, State	Standards	BAT, BPT	Periodic, Every 3 years (State)
Sweden	Federal, some local flexibility	Standards	BPM	Comprehensive, as technology changes
Germany	Federal, Lander	Standards, Effluent Charges	BPT, C.A.	Periodic, Comprehensive
Canada (Ontario)	Federal, Province	Standards	BAT (MISA)	Periodic

The various policy instruments used reflect a similarity in relations between national governments and local governments. In the case of the US, Germany, and Sweden, water quality standards are set at the level of the national government, with enforcement devolved to either local governments, or regional offices of a national environmental protection agency. While some degree of local flexibility occurs, the national-local relationship is typically one of organization and enforcement. In Ontario, a slightly different situation exists. Although firms are subject to federal legislation, the provinces are permitted to set their own regulatory agenda (provided of course the standards don't fall below a federal minimum). In addition, they are permitted to adopt their own enforcement mechanisms. Consequently, a system of technology-based permits targeting all firms, and performance-based standards targeting direct dischargers, operates in Ontario. Although this is similar to the relationship

[8] Refers to Technological Approach: BAT (Best Available Technology), BPT (Best Practicable Technology), C.A. (Commonly Accepted Technology), BPM (Best Practicable Means).

between the German policy instruments, Ontario's approach varies from that of other provinces.

Sweden and Germany are similar in their review of the conditions of their legislation. In the case of Sweden, standards are reviewed periodically in a comprehensive fashion to guard against the deterioration in water quality. In particular, a close watch is kept on advancements in compliance and production technology resulting in a ratcheting upwards of the standard to reflect a new technological benchmark. This is facilitated by the fact that standards are developed in consultation with all stakeholders including environmental technology suppliers. In Germany, although the standard-setting procedure is not as co-operative, governments are aware of advancements in compliance technology and are able to adjust standards accordingly (Pehle 1997). In both the US and Canada a periodic review process is undertaken by the regulatory agencies, however, it is not as comprehensive as either Germany or Sweden.

Despite the similarity in the use of technological benchmarks to define water quality standards in these international examples, Canada has been slow to adopt them. The MISA programme in Ontario is the only example in Canada where this technological approach has been used (MacDonald 1991). Moreover, the MISA programme was not introduced until 1986 (and not fully implemented until 1995-96), a long time after other jurisdictions had been using this technological approach. Canada therefore, when compared with other jurisdictions internationally, has been a 'regulatory follower' with regard to water pollution regulation. One of the consequences is that foreign-owned firms in Canada may have access to technology developed by their parents or affiliates in the US or elsewhere. This technology may have been developed in response to the regulatory climate in the parent's or affiliate's location. Therefore, it is necessary to take account of the response to environmental regulation by indigenous and transnational environmental technology firms. This issue is explained further in the following chapters.

Chapter 3: The Impact of Environmental Regulation on Innovation

3.0 Introduction

The theoretical literature on innovation and technological change provides few references to the impact of environmental policy on technology development. Nonetheless, a number of important works have emerged in recent years that contribute to our understanding of this technology-policy relationship. In this chapter I explain the seminal contributions of these earlier writers, and evaluate their models of the dynamics of the technology development process. Finally, an environmental-innovation model is developed, the strengths of which are empirically tested in the subsequent chapters.

The chapter begins with a discussion of the work of Michael Porter, and Nicholas Ashford, who are key contributors to ideas on the relationship between environmental policy and technology development. A major limitation of their work however, is that it is very general in its focus and lacks specificity about the innovation process, particularly at the level of the individual industrial firm. Nevertheless, their work does provide a useful starting point for a model that has the relationship between environmental policy and technology development occurring within an industrial innovation system.

The theoretical point of departure for this review is innovation theory since it is valuable to view environmental regulation as yet another potential stimulus of the innovation process.

3.1 Innovation Defined

Technological innovation can be defined as "the technical, design, manufacturing, management, and commercial activities involved in the marketing of a new or improved product or the first commercial use of a new or improved process." (Freeman 1982). It is a much more complex process than the mere act of invention because it involves the commercialization of a new product or process technology. Consequently, it is not a simple function of high levels of R&D, but rather a complex process that includes research, design, engineering, and testing prior to market entry (Britton et al 1996).

Freeman and Perez (1988) characterize the type of innovation itself as a minor adaptation, a major adaptation, or radical new product or process. In particular, they classify innovation as being of two principal types according to its attributes. This classification is as follows:

(1) *Radical* innovations tend to be large-scale advancements in the technology. Generally, they are parts of a discontinuous process, occurring usually as a direct result of research and development, and resulting in major product or process changes. Examples could include the automobile, the jet engine, or the semiconductor.

(2) *Incremental* innovation is a continuous process that results in the steady improvement of the product or process. These small-scale innovations are more often the result of design or engineering suggestions rather than any deliberate program of research and development. Examples could include the step from the Pentium 200MHZ computer processor to the Pentium II processor.

Both radical and incremental innovation can be combined to observe what Freeman and Perez (1988) call '*Changes in the Technology System*'. Here, in addition to radical and incremental innovation, changes also occur in the managerial and organizational structure of firms. Technological change is so far-reaching, that new sectors producing a whole new range of products and processes emerge. The environmental technology industry has not quite reached this stage of evolution.[1] However, as more environmentally sustainable industrial activity occurs, it is possible that a 'green' technological system may emerge.[2]

3.2 Existing Models of the Environmental Policy-Technology Development Relationship

3.2.1 The Porter Hypothesis

Porter (1990) advances a model of the relationship between environmental policy and technology development, through his broader model of national competitiveness. Using his 'diamond of national advantage' (Figure 3.1), he illustrates the components of national competitive success. This diamond consists of four key integrated components:

Factor Conditions: the factors of production held by the nation including pools of skilled labour, technology, and infrastructure.

Demand Conditions: the presence of sophisticated local demand that induces firms to innovate.

Related and Supporting Industries: The presence of competitive local suppliers of specialized

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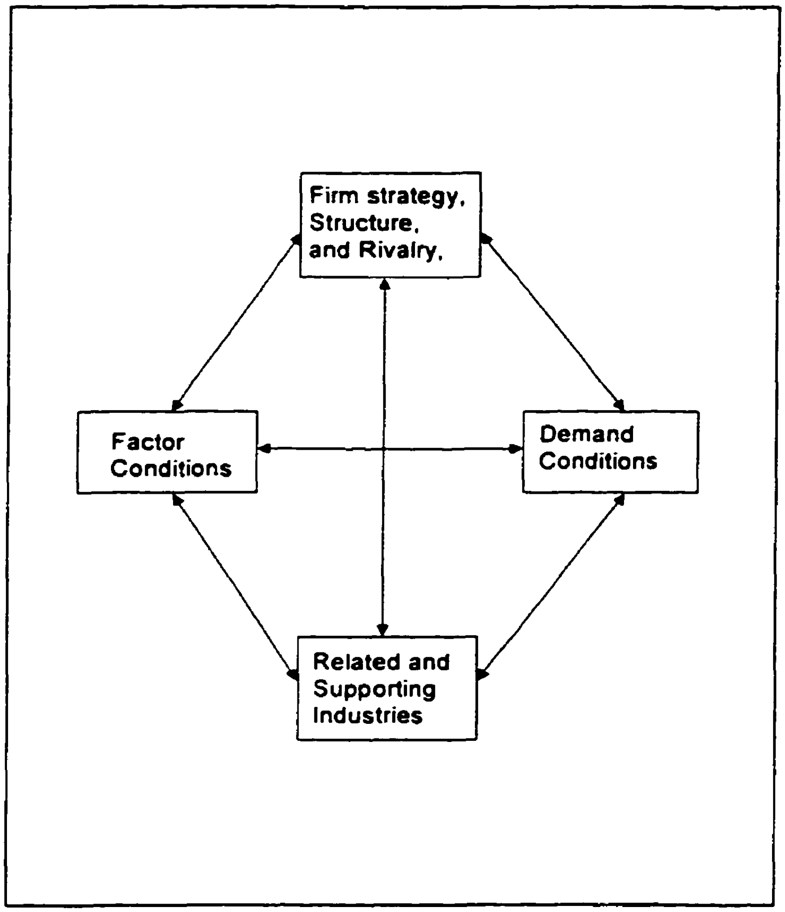
[1] In terms of environmental technology, both end-of-pipe and process-integrated technologies are technological approaches to achieving compliance. Kemp (1997) specifies that the 'standardized' approach is end-of-pipe. However, as will be indicated in Chapters 5 and 6 some end-of-pipe technologies are very innovative not yet having reached the end of their product life cycle. Therefore, both technological approaches will contain individual radical and incremental innovations.

[2] See Kemp and Soete (1992), and Freeman (1993).

inputs, and firms who possess complementary skills and technologies.

Firm Strategy, Structure, and Rivalry: The conditions of the local environment in which firms operate. These local conditions will influence the structure and organization of industrial firms.

Figure 3.1: Porter's Diamond of National Competitive Advantage



Source: Porter 1990

Government policy plays a role in Porter's model of competitive advantage by influencing the generation of linkages between the different components of this diamond. As such, government policy does not directly determine competitive advantage, instead it helps facilitate the creation of linkages between two or more of the components of the model. The stronger these linkages become, the more integrated the national economic system becomes, and the more competitive the nation becomes.

Through the implementation of regulatory policy in particular, government can affect the demand conditions within the national economy. These regulations may affect what products are manufactured and how they are manufactured. In terms of environmental regulation, Porter argues that firms that are subject to compliance with its conditions will be forced to re-organize their production systems such that they may change their product focus, or change the process by which their products are manufactured. It is through changes in the manner in which manufacturing occurs, that Porter's approach to understanding the environmental policy-technology development relationship can be addressed. It is this portion of Porter's model that, in environmental economic circles, has been dubbed the 'Porter Hypothesis' (Doering et al 1992, Jaffe et al 1995).

According to the Porter Hypothesis, environmental regulation can have a positive impact on a nation's competitiveness. The need to comply with the conditions of the regulation will force firms to become more innovative as they re-organize their product line, or the manner in which their products are manufactured. Consequently, the regulation is said to generate an 'innovation-offset' as the regulated firms will be able to offset the cost of compliance through innovation. It is when the regulation induces the firms to restructure their manufacturing process that the Porter Hypothesis will have its most profound impact on the competitiveness of the environmental technology industry.

Figure 3.2: Porter's Model of the Regulation-Industry Development Linkage

Source: After Porter 1990

A graphical representation of Porter's argument for the impact of environmental policy on the competitive development of environmental technology suppliers is provided by Figure 3.2. As the regulated firms adjust their manufacturing activity to achieve more environmentally benign production, under the influence of environmental regulation, a demand for environmental technology is created. Domestic suppliers ('Related and Supporting Industries', in the diamond) of environmental technology will be induced into satisfying this newly created demand. As the regulations change or are ratcheted upwards, demand for compliance technology will become greater, and the environmental technology industry will grow stronger. If the regulations are stricter than other jurisdictions or are set in anticipation of international regulatory changes, the domestic environmental technology industry will be able to gain an early mover advantage in the export of compliance technology. This early-mover advantage due to anticipatory regulatory change is represented by the arrow from environmental regulation to the environmental technology industry. So Porter implies that there is a direct link between environmental regulation and the growth and development of a successful environmental technology industry. The shaded portion of the model between the Regulated Firm and the Environmental Technology Firm, indicates the innovation process underpinning the actions of the environmental technology firms exists within a 'black box' (Rosenberg 1992, 1994).

The essence of Porter's approach to the environmental policy-technology development relationship is that environmental policy is presented as having an important role as an industry generator. The increased demand for compliance technology will lead to the establishment of a competitive environmental technology sector, and thus strengthen the linkages between the 'Demand Conditions' and 'Related and Supporting Industries' components of the Diamond (see Figure 3.1).

Porter does not test his proposition though he does provide some empirical support for the regulation-technology development relationship using a number of anecdotal sources. Solvell, Zander, and Porter (1992) argue, for example, that the competitive success of the Swedish environmental technology industry has been due to its strong linkages with the resource-processing sector. These linkages have been facilitated by the stringency of Swedish environmental policy. The success of ABB Flakt[3], one of the most successful suppliers of environmental technology, was primarily due to their links with the Swedish mining industry that provided a testing environment for their technology. In the case of Canadian resource industries, Porter (1991) argues that the Canadian Pulp and Paper industry bought Scandinavian process technology because the Scandinavian firms had a competitive advantage in the supply of this technology. He suggests that the early mover advantage possessed by these firms was generated by the tough environmental regulations in Sweden, and the strong links the environmental technology firms had with Swedish pulp and paper firms.

Although Porter argues that the Swedish environmental technology industry has emerged since of the introduction of stringent environmental regulations, he is probably overstating the presence of a direct link between the development of the industry on one hand, and the application of stringent environmental regulation on the other. Solvell, Zander, and Porter (1992), in trumpeting the success of environmental technology development in Sweden, also note that Flakt was in fact, a mining equipment manufacturer before its merger

[3] ABB Flakt was created through the merger of Asea Brown Boveri (ABB) who were manufacturing

with ABB. Therefore, the development of environmental technology by ABB Flakt was less an example of the new firm emerging in a new industry, than an existing firm diversifying its activities within a highly fragmented, and already existing, machinery and equipment market.

The fragmented structure of the larger machinery and equipment supply market is equally true for Canada. There are, for example, 29 4-digit manufacturing 'industries' producing different types of machinery and equipment, and there is no official SIC designation for the environmental technology industry. Industry Canada has subsumed it under SIC 3199 Other Machinery and Equipment Industries NEC (not elsewhere classified), but intensive examination of the firms who manufacture environmental technologies shows that in Canada as in Sweden, many also manufacture other, 'non environmental', machinery and equipment.

The example of Canadian pulp and paper firms adopting Scandinavian process technology also has to be interpreted in light of a pre-existing relationship with a larger machinery and equipment industry. Canadian pulp and paper mills have had a long history of purchasing Scandinavian pulp and paper technology (Britton and Gilmour 1978, Hayter 1988, 1996). In some cases the suppliers of pollution control and prevention technology are also supplying pulp and paper process technology, because the firms are operational within a number of market segments of the existing machinery and equipment industry. Additionally, it is unknown from Porter's evidence, if the Canadian pulp and paper firms purchased the Scandinavian technology solely for environmentally related reasons; if the technology was purchased because of an existing relationship with these technology suppliers; or indeed

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air-handling equipment, and Flakt who were a manufacturer of mining equipment.

because the Scandinavian technology held a number of different benefits for the pulp and paper firms, environmental reasons being just one of them.

What this evidence points to is an already existing relationship between the suppliers of machinery and equipment and the users of that technology. Environmental technology is something that is added to that relationship. Consequently, any argument concerning the role that environmental regulation has played in the development of the environmental technology industry has to be made with reference to an existing relationship between technology producers and technology users. Further, it would be inappropriate to argue that regulation alone has led to the development of the machinery and equipment firms supplying environmental technology because this would ignore the complexity of the ongoing process of innovation. Although the regulations may have induced the technology producers and users to come together in a new round of innovation, the advancement of the environmental technology industry may be based on the innovation relationship they already have with their technology users. Therefore, only by first understanding the nature of the innovation process that underscores the relationship between the technology producers and their customers, will the role that environmental regulation plays in the technology development process be understood.

3.2.2 Ashford's Model of the Regulation-Technology Development Linkage

The model proposed by Ashford (1994, 1993, Ashford et al 1985) differs from that of Porter in that it is a model of technology development rather than a model of industry development. In other words, Ashford presents the relationship between environmental regulation and technology development in terms of modeling the technological response by various industry actors to the stimulus of environmental regulation (Figure 3.3).

According to Ashford, environmental regulations will elicit a technological response from either the firm subject to the regulations, or the environmental technology industry. In some cases, both will act at the same time. When the regulated firm reacts to the regulation, a number of different technological outcomes may result. If the regulations prevent the manufacture of particular products, as in the case of ozone-depleting CFC's regulated under the CEPA, the firm will be forced to change the nature of inputs into its production process. This may mean the use of less harmful CFC substitutes in refrigeration systems, or as aerosol propellants. It may also mean that the firm reformulates the nature of its final product. For example, the firms that actually produce the propellants, or the coolants may be forced to manufacture gases that are less damaging to the Ozone Layer. Lastly, the firm may be forced to re-organize its manufacturing process in cases where it produces toxic substances as a byproduct. An example of this can be found with the pulp and paper industry where limits have been placed, through the Pulp and Paper Regulations contained in the Canadian Fisheries Act, on the discharge of AOX.[4] This has prompted pulp and paper firms to restructure the bleaching process, to reduce the production of AOX , and in some cases to adopt a more environmentally benign process altogether.

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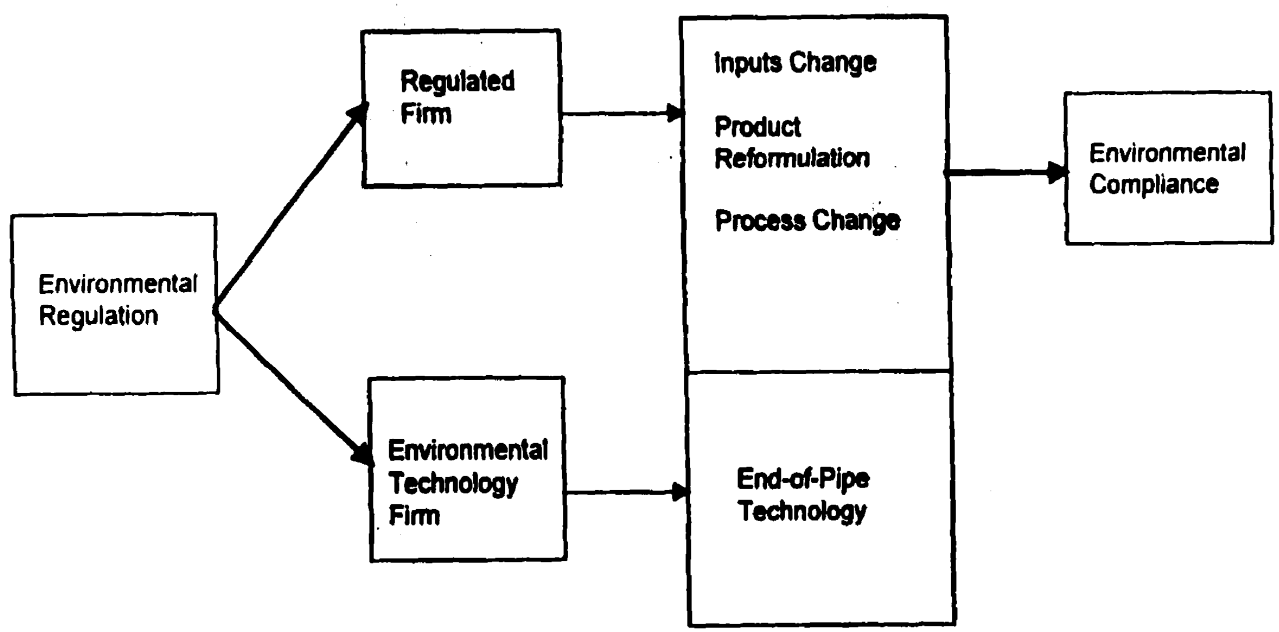
[4]Absorbable Organo Halides (AOX) are chlorinated organic substances that are produced as a byproduct of the bleaching process in kraft pulp mills. These substances, which include dioxins and furans are carcinogenic agents, and are also responsible for birth defects (Estrin and Swaigen 1993).

Figure 3.3: Ashford's Model of the Regulation-Technology Development Linkage



Source: after Ashford 1993

In addition to regulations spurring a technological response on the part of the regulated firm, they may also influence the direction of activity within the environmental technology industry too. These firms may be induced to develop technologies that bring the regulated firms into compliance. Ashford (1994, p. 298) actually refers to these technologies as pollution control devices, suggesting that the response to regulation will be the development of end-of-pipe controls as opposed to the development of technologically advanced pollution prevention systems.

Ashford, unlike Porter, argues that his bifurcated response model is a model of innovation that can be used to predict technological responses to environmental regulation, and accordingly, it can be used by policy makers to guide the development of environmental regulation. Depending on the technological goals of the regulatory agency, a particular set of regulatory instruments can be used as a method of achieving those goals. Therefore, Ashford argues that the innovation process can be predicted, and the technological characteristics will determine the direction of future innovation. At the heart of this argument is the assumption that the agency setting the regulation is aware of the technological capabilities of both sets of potential respondents -the regulated firms and the environmental technology industry- and can thus elicit the desired technological response. In other words, it is the regulatory agency that determines the rate and nature of innovation. Ashford (1994) puts it as follows: "...the theory relies on the assumption that the regulatory designer can determine the extent of an industry's innovative rigidity (or flexibility) and its likely responses to the regulatory stimuli..." (p300).

The model describes a theoretical relationship between regulation and technology development in which the type of regulation, whether it is technology-based or performance-based, will determine the type of technological response made, and who the particular responder will be. If the goal of the regulator is to stimulate the production of pollution control technology, then a technology-based standard will be implemented. The use of technology-based standards will result in the use of pollution control technology that will be supplied by the environmental technology industry. Likewise, if the regulator wishes to stimulate a more fundamental change in the nature of the firm's manufacturing process, then a performance-based standard will most likely be used.

With Ashford's model, a little more is known about the innovation process compared with Porter's model. However, neither Ashford nor Porter provide a thorough consideration of the process of innovation at the level of the firm.[5] The relationship between the regulated firm and the environmental technology firm can be considered a 'grey box' rather than a 'black box', as it specifies an incomplete innovation process. While Ashford insists that his model demonstrates the nature of the innovation process governing the technological response to environmental regulation, he gives actions of the firms little attention. Furthermore, he fails to consider the dynamics of the innovation system that occurs among firms manufacturing pollution control (or prevention) technology.

Although Ashford describes two regulatory initiatives, his analysis is strongly oriented towards the actions of the regulated firm and he fails to specify how the environmental technology industry is called into action. In a model of innovation, the actions of the environmental technology industry would be addressed, in particular the circumstances and conditions of the process that governs the development and manufacture of their

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[5] Porter's and Ashford's use of the term 'firm' is simply in the context of a member of an industry

technology. Ashford implies (as does Porter) that the environmental technology industry will manufacture pollution control technology, essentially in an off-the-shelf fashion. While this may be the case with some end-of-pipe technology, it is not a universal pattern. Furthermore, process-integrated technology always needs to be incorporated into the capital equipment of regulated firms that are already active in the production process. Therefore, Ashford's model fails to specify the nature of the linkage between the environmental technology firm and the regulated firm, and the linkage between the environmental technology firms and the 'process change' category of technological responses. Further elaboration of these linkages in terms of process-integrated technology is needed, as it is for end-of-pipe technology.

3.3 Advancing a new model of the Environmental Regulation-Technology Development Relationship.

The previous section has reviewed the existing theoretical approaches to understanding the relationship between environmental regulation and the development of environmental technologies. Although these existing models are useful as an initial attempt to understand this relationship, they lack a clear articulation of the complexity of the innovation process. This is strange considering innovation theory has been an active field of research among many social scientists especially economists, and much of this work has evolved while Porter and Ashford have been writing on the subject.

The role of environmental policy as a stimulus for innovation, needs to be addressed in the context of a broader discussion of the institutional drivers of technical change. These stimuli,

rather than as an individual producing unit.

that can be public or private in nature, include capital outlays, physical infrastructure, supplier-user linkages, flows of information, technology, science, and people, and government rules and regulations (Niosi et al 1993, Freeman 1993, 1997). The institutional basis of technological change can be thought of as constituting part of an innovation system that is codified at the level of the nation state (Lundvall 1988, 1992, Freeman 1997) or the region (Amin and Thrift, Storper 1995, Pratt 1997, Wiig and Wood 1997). Broadly, the concepts of a national, and a regional innovation system capture the varying abilities of nations and regions to take advantage (or not) of the process of technological change within the context of political and socio-economic institutions (McKelvey 1991, Nelson 1993, Edquist 1997, Freeman 1997). Environmental policy can therefore, be thought of as part of a national or regional set of institutional arrangements, that will serve to influence innovation at the level of the environmental technology firm.

Consequently, in this section I address the failure of existing models to account for the nature of the innovation process and propose a revised model that focuses directly on innovation at the level of the individual firm. Before discussing the characteristics of this revised model, the organization of the innovation process is considered at a more generic level.

3.3.1 Characterizing the Innovation Process

Innovation, which was defined earlier in this chapter, has traditionally been though of as a linear process occurring at the level of the firm. Under this assumption, innovation proceeds in a logically sequential fashion through a series of stages, from research, through development, to production and marketing. The process is driven by either the needs (perceived or actual) of the market, or scientific discovery, thus providing for two distinct and exclusive models of innovation - market pull, and technology push (Rothwell and Zegveld 1985, Kline and Rosenberg 1986, Rothwell 1992b, Hall 1993, Freeman 1994).

This assumption of linearity is clearly evident in the approaches of Porter and Ashford, who appear to view innovation as a simple stimulus-response process. Porter perceives regulation as stimulating demand for environmental technology by the regulated firm. The environmental technology firm will then supply technology in order to meet that demand. For Ashford, the regulation will stimulate the environmental technology firm to produce technologies that may then be supplied to regulated firms in an 'off-the-shelf' fashion. Both approaches assume that innovation occurs as a linear series of steps, stimulated by regulation at one end and producing technology at the other.

What this simple linear approach fails to capture is, something that many innovation theorists recognize, that innovation is a complex and dynamic process involving both the technology producer and the technology user. Freeman and Soete (1997) suggest that innovation tends to be more successful in an environment where knowledge of both the technological needs of potential users and the technological capabilities of producers is generated. Consequently, innovation can be viewed as an interactive process, and innovation models should take account of this. In developing a model of innovation in the environmental technology industry, three important themes will be addressed reflecting this interaction. First, innovation is a knowledge intensive activity, second, this knowledge intensity influences the governance of transactions among the actors in the innovation process, and third, firms that hold stocks of specialized knowledge will emerge as specialized suppliers. These three issues help an understanding of the interactive nature of the innovation process, and as a result should be at the heart of an innovation model.

Knowledge intensity of innovation

The theory that innovation results in the creation of knowledge that eventually becomes embedded in a new technology is fundamental to any understanding of how an innovation process should be modeled. This is because it allows recognition of the interaction that occurs between the producers and users of technology, as innovation proceeds.

David (1986) argues that technologies, and hence the process by which they are developed, are not static. Instead, they evolve as development and subsequent diffusion occurs. Dosi (1988) also advances the proposition of a non-static innovation process, stating that it is a dynamic system that evolves as a result of knowledge creation. Technology evolves incrementally through modifications suggested by those who produce the technology, or as a result of suggestions by those using the technology (von Hippel 1988, Riggs and von Hippel 1994). The small improvements or advancements in design and engineering can be an important source of competitive advantage for firms (Porter 1990, Langdon and Rothwell 1985). Rothwell (1990) argues that the most successful technology producers will experience a strong communications intensive relationship with their customers.

Rosenberg (1982, 1994) asserts that the diffusion and subsequent improvement of technology is a learning process, the length of which is governed by the complexity of the new technology and the existing knowledge base of the technology users. Dosi (1988) differentiates between three types of knowledge. The first is a general scientific knowledge that is common to all firms or individuals performing research, it includes general laws of science or engineering. The second is a specific knowledge that is exclusive to a particular technology, while the third is what Dosi calls *tacit* knowledge that are the accumulated skills acquired inside the firm. These skills or capabilities are not easily transferred through the market. This latter knowledge is similar to learning by doing and learning by using as advanced by Arrow (1962), Rosenberg (1982, 1994) and von Hippel (1988), and it is only over time that this tacit, firm specific knowledge may become codified, and thus more generally available (Maskell and Malmberg 1999). The level of technological skill within the firm will define how quickly the technology can be utilized, and as a result the speed of information generation regarding its use. This skill level maybe quite specialized and specific to that firm, and the information gathered as a result of the technology manufacture eventually becomes assimilated as a design improvement.

Transactional nature of innovation

Placing innovation in the context of the creation and use of knowledge, allows a link between the technology producer and the technology user to be observed, and thus for a dynamic iterative innovation model to be established. However, it is not always the case that the technology producer and user are separate firms linked together through innovation. In some cases the producer of the technology is also the user of the technology.

What is central to an understanding of why the innovation process occurs within the same firm or between firms, is the theory that explains the organization of firms in terms of a set of transactions that link together the various components of manufacturing activity. In terms of the innovation process, these transactions include the acquisition of technology and information about the technological capabilities of producers, and the technological needs of users. The transactions can occur externally through the functioning of the market, internally through an organizational hierarchy, or through some hybrid form, for example through subcontracting, joint ventures, or strategic alliances (Williamson 1985, Johansson and

Mattsson 1987). The boundary between internal, external, or intermediate transactions is, according to Williamson (1985), established through the costs associated with each organizational form (Williamson 1985). If the costs of acquiring information and knowledge in the market are substantial, the firm will internalize its transactions through vertical integration, or may engage in some intermediate relationship with another firm. Johanson and Mattsson (1987) suggest that the usefulness of the transactions cost approach to explaining inter-firm linkages is "related to its ability to explain the existence of different governance structures or institutional forms in different situations."

Lundvall (1988) takes a different approach to explaining the transactional nature of innovation. In suggesting the transactions cost approach is too narrow in its focus, he argues that most markets can be classified as 'organized markets'. These represent a combination of market elements involving price and volume with organizational elements involving qualitative information flows, and cooperation between firms. An important feature of the interactive process of innovation is the close connection between the producers and users of technology. These connections can be placed on a spectrum ranging from a simple arm's length supply relationship to a very complex cooperative relationship where both producers and the users collaborate to create new technology. The nature of the inter-firm relationship will vary according to the complexity of technology involved. Technologies that are more complex, and are non-standardized will tend to require closer interaction between the technology producers and users (Lundvall 1988, Gertler 1993, 1995). On the other hand, where technology is simply bought 'off-the-shelf', a close interactive relationship between the technology producer and user is less critical. Ahearn (1993) argues that, in the case of small Canadian high technology firms, strategic alliances are used to exchange technology because the inability of markets or organizations to do the task. These alliances are an important strategy particularly for small R&D intensive firms to follow in order to gain access to international markets. This is fueled by the limited sized of the Canadian market for many high technology products and processes. As a result, intermediate forms of organization such as alliances, joint ventures and subcontracting can function as conduits to allow these firms to gain a competitive foothold internationally.

Emergence of 'Specialized Suppliers'

Pavitt (1984) refers to firms that hold stocks of specialized and tacit knowledge, and are able to exploit it through inter-firm linkages as 'Specialized Suppliers'. Typically, these firms are small, highly specialized producers of machinery and instrumentation. Their technological output tends to be focused more on products that enhance the performance of their customers, rather than on process innovations aimed at exclusively reducing cost. Consequently, they retain a close relationship with their customers, one that focuses on design improvements, the customization of existing products, and the building of new products for specific customers.

Pavitt (1984) argues that the specialized suppliers have a complementary relationship with their customers, and this is important for the process of technological change. Teece (1986) also makes the argument that complementary relationships between firms are important for the process of innovation. Successful innovation occurs in an environment where technical knowledge in one firm is combined with technical knowledge in another firm, to produce a new product or process. Freeman and Soete (1997) recognize the importance of the interdependence between user and producer, arguing that both are complementary rather than independent or mutually exclusive of one another. Rothwell (1990) who argues that the most successful technology producers will experience a strong, communication intensive relationship with their customers also addresses this theme. While information flows are important at the production stage of the technology and beyond, they are of vital importance at the design stage. Good communications between customers as well as other external sources of ideas are key, for the success of technology producers, especially at the design and engineering phase of innovation. Rothwell (1990, 1994a and b) and Rothwell and Dodgson (1991) argue that this is especially important in the case of small and medium sized enterprises that may be limited in their technological and design expertise.

3.3.2 Interactive Innovation Models

Innovation, so far, has been discussed at the generic level in terms of a dynamic process involving the interaction between the producer and user of the technology. The traditional linear approaches to modeling innovation fail to capture this dynamism, as do the models of both Porter and Ashford. Consequently, they are weak informants of the relationship between environmental regulation and the development of environmental technology. Because the development of new technology embodies the creation and use of knowledge, and the necessity to obtain knowledge and information results in the producer and user of technology interacting, a better model of the innovation process needs to recognize this dynamic.

As a reaction against the over-simplistic linear models of innovation, a number of more complex, interactive models have been devised over the years. These models, of which the *chain-linked model* (Kline and Rosenberg 1986), and the *coupling* or *interactive model*

(Rothwell 1992b, Rothwell and Zegveld 1985) are the most notable, recognize that neither technology push nor demand pull are all powerful in the innovation process (see Appendix 3 a and b for diagrams). Instead, innovation is a complex, iterative process that includes scientific discovery and the needs of the marketplace occurring alongside production, marketing and distribution.

Kline and Rosenberg's *chain-linked model*, that had been adopted by the OECD, focuses on the interactions between the various phases of innovation, in particular, the feedback mechanisms that take place.[6] Because of the existence of these feedback loops, the model illustrates the iterative nature of innovation. These iterations can occur within the innovating firm as the process advances, due to the occurrence of 'learning by doing' or through 'learning by using' as the technology is used. They may also occur through a process of 'interactive learning'. This, Lundvall (1997) argues, occurs as the actors in the innovation process interact and share knowledge, especially tacit knowledge.

Unlike the linear models that always begin with either a technological discovery, or a market need, innovation in the chain-linked model can begin or be stimulated by either or with both, or with redesign and engineering. Consequently, the chain-linked model allows for multiple entry points. For Kline and Rosenberg, the dichotomous linear model is somewhat redundant, as the separation of technological discovery from the needs of the market place is artificial. They argue that if the process begins with a market need, a new technological design will result, and the new knowledge that design has generated will lead the process of redesign. Likewise, the outcome of the system 'pushed' by scientific or technological

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[6] See OECD (1994) and Industry Canada (1994b).

discovery, will be new market conditions. These will then fuel further rounds of innovation, as the cycle continues. Therefore, this interactive chain-linked model presents the innovation process in a cyclical light.

In this model, primary place is given to knowledge and research that occurs throughout the process. Because of the iterative nature of the model, flows of knowledge are continuous. It is only when a technological bottleneck cannot be solved by the existing body of available knowledge, that the linkage to research is employed. As the bottleneck is solved and the system proceeds, that research is incorporated into the existing stock of available knowledge. So, in a fundamental way, knowledge and interactive learning drive the whole innovation system.

Rothwell 's *coupling model*, like that of Kline and Rosenberg, describes innovation as an interactive process that "represents the confluence of technological capabilities and market needs within the framework of the innovating firm" (Rothwell and Zegveld 1985, p 50). Although the role that knowledge plays is not as explicit as under Kline and Rosenberg, the existence of feedback elements linking the various stages suggests the occurrence of learning-by-doing, learning-by-using, or 'interactive learning'.

While these interactive models of innovation provide a good explanation of the process through which new technological change occurs, they don't specify the relationship between the various actors involved. In particular, they don't discuss the linkages that could occur between the producers and the users of technology. As a result, it difficult to understand the governance structure that may exist within these models and this is crucial to developing a model of the linkage between environmental policy and the development of environmental technology.

3.3.3 Linking Innovation and Environmental Policy

The innovation system, left to its own devices, is a weak producer of environmental technology, whether the end-of-pipe or process-integrated form of technology. Nevertheless, as noted in chapter 2, industrial firms fail to take account of the social costs of their actions and left unregulated, environmental degradation occurs. Policy has been proved a necessary intervention to preserve environmental quality, and many governments have made serious efforts to steer the innovation system in this direction. However, it is not immediately obvious from these interactive models, how environmental policy may be adequately incorporated into the process.

The difficulty in applying environmental policy to the existing interactive models of innovation is that different policy instruments exist. In the Kline-Rosenberg model for example, the central chain of innovation may begin with a potential market and end with the realization of a market. In this arrangement, policy can be thought of as powering the innovation system, by manipulating the market, and creating a need for a technological solution. As innovation proceeds in an iterative and interactive fashion, that technological need will be satisfied. In the case of performance standards, this interpretation seems valid enough as the policy instrument does not mandate the application of specific technologies. Firms, therefore, are forced to interact in order to ensure the user firm adopts appropriate technology for compliance. The model also holds true in cases where process-integrated technologies are the outcome of an iterative development process.

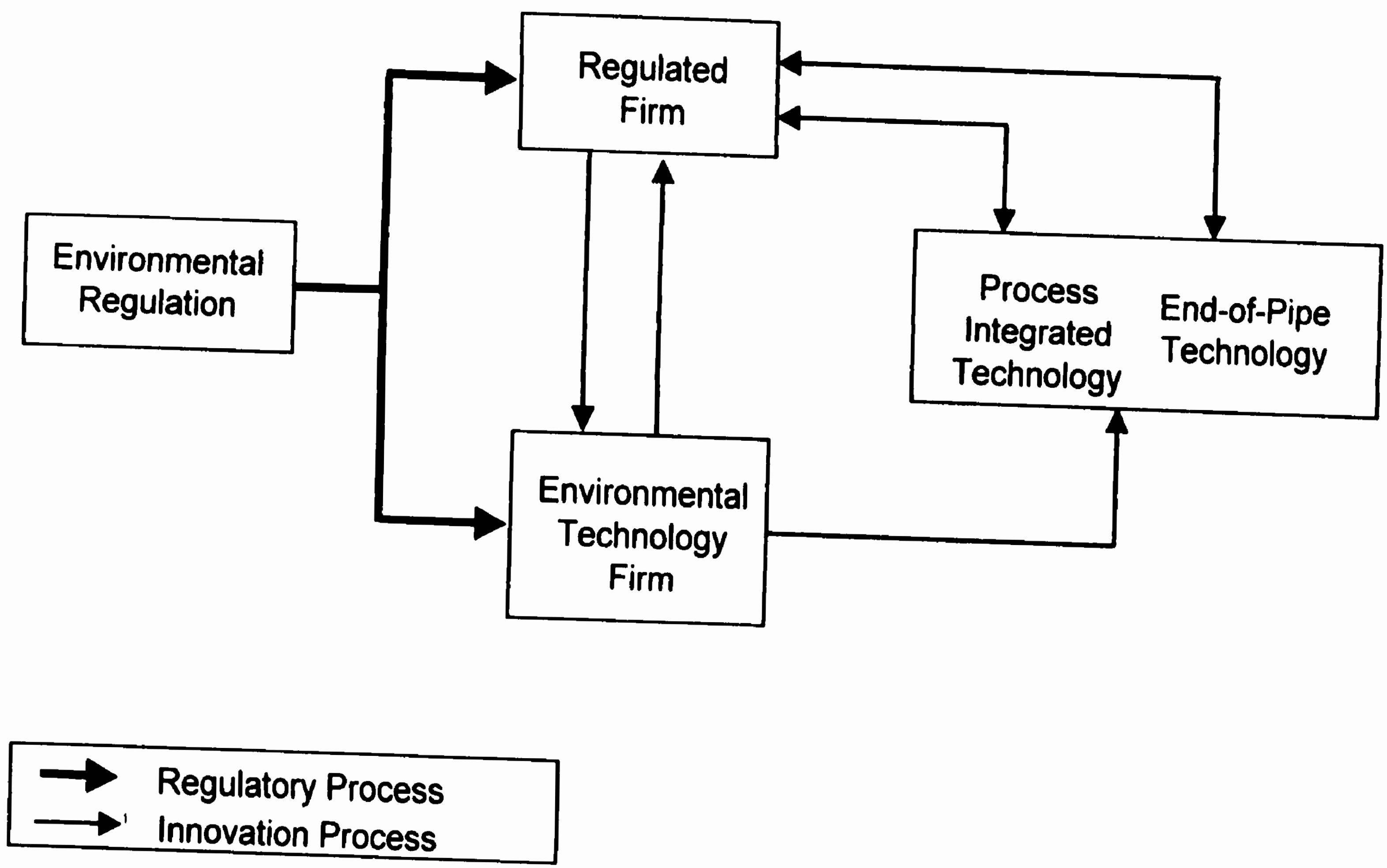
In the case of technology-based standards however, it is possible that the model will not describe the policy stimulus of innovation as the instrument requires the application of specific, predominantly end-of-pipe, technologies. This lends itself to limited interaction in the process of technology development, as it assumes the environmental technology firm is completely knowledgeable about the technical requirements of the policy instrument and will thus supply technology to the market, essentially in an off -the-shelf fashion. In effect, a direct policy-technology supplier link must be modeled. This 'direct' technological relationship needs to include the possibility of solutions being developed in-house by the regulated firm, externally by the environmental technology firm, or through some joint arrangement between both actors. What this indicates is that a specific purpose environmental-innovation model needs to be devised that recognizes that innovation is a dynamic, knowledge intensive process that allows for the development of both end-of-pipe and process-integrated technologies under different policy regimes.

3.3.4 An Environmental-Innovation Model

It is possible to portray the relationship between environmental policy and the development of environmental technology (Figure 3.4), in a fairly simple diagram.

It is an iterative model, recognizing the knowledge intensive nature of innovation and acknowledging the importance of the existing iterative innovation models. But it is also more specific than existing models as it describes the relationship between the producers of and the users of environmental technology, when different policy instruments are applied and when different technological choices prevail. Environmental policy is a fundamental part of the system, not something that is merely retrofitted onto an existing innovation model.

Fig. 3.4: An Environmental-Innovation Model



Although the model distinguishes between a regulatory process and an innovation process, they are both fundamental to the operation of the environmental-innovation system. The regulatory process captures the different policy instruments that can be employed to protect environmental integrity. The application of a technology-based or a performance-based approach might be expected to result in a different pathway through the model.

Porter argues for an indirect relationship between regulation and an environmental technology industry, and Ashford argues for a direct relationship, though only in the case of end-of-pipe technology. The approach I have adopted however, allows the relationship to be both direct and indirect, and the model accommodates different policy choices. There is a basic bifurcation from environmental regulation to each category of firm, since the model begins with environmental regulation acting as an initial stimulus for the development of end-of-pipe or process-integrated technologies, on the two sets of firms. As discussed in chapter 2, the application of technology-based standards to control industrial pollution tends to result in the adoption, and thus manufacture by technology producers, of end-of-pipe technology as opposed to process-integrated technology. This is also supported by Ashford's model discussed above. Kemp (1997) argues that firms prefer the installation of end-of-pipe technology, as it can be easily incorporated into existing production processes. Innovations that are additions to existing processes and are simple to use requiring short installation times, tend to have faster rates of adoption than complete replacements of existing technology (Brown 1981, Gertler 1993). Kemp (1997) provides an example of such an innovation with the development of CFC alternatives. The Montreal Protocol of 1976 requires the elimination of CFC's from cooling technology by the beginning of the next century. This requirement has stimulated the search for alternatives to CFC technology.

However, the search has deviated little from the existing CFC trajectory because much of the development has centered on manufacturing 'soft' CFC's that have little or no ozone depleting potential. These new CFC's are easily incorporated into existing cooling and refrigeration systems. Lundvall (1988) submits that less complex technologies will typically be produced by technology manufacturers and supplied in an off-the-shelf fashion.

As the dominant approach to controlling pollution in Ontario is through the application of permits that typically require the regulated firms to install specific technologies, a direct relationship would be expected between environmental policy and the environmental technology firm. The environmental technology firms would then supply end-of-pipe technology to the regulated firms in an arm's length way. Because this is an iterative model, some 'learning' may occur as the regulated firm uses the technology, and accordingly, there will be some communication back to the environmental technology firm. This may involve adjusting flow rates on wastewater streams, or indeed, adjusting the technology if the permit requires an increase in the quality of effluent. So, there may be some degree of *ex post* interaction between the regulated firm and the environmental technology supplier.

In the case of performance standards, the regulated firm can employ whatever means it sees as appropriate in order to achieve compliance. Technologically, this may involve the installation of process-integrated technology, though not exclusively. Some firms may in fact, deem end-of-pipe technology to be the most appropriate method for achieving compliance according to their particular production function. In responding to the regulation, the regulated firm will have a number of choices regarding the organization of their technological transactions. They may decide to develop a technological solution in-house, they may purchase a technology off-the-shelf from an environmental technology firm, or, they may cooperate in the development of a technological solution with an environmental technology firm. In each of the various choices made by the regulated firm, there will be varying degrees of interaction.

While Ashford states that the relationship between the environmental technology firm and the regulated firm is solely an arm's length supply relationship, in my model the whole spectrum of producer-user relationships may occur. As stated earlier, the dominant approach to environmental policy in Ontario is the technology-based permit that tends to reinforce the use of end-of-pipe technology. In addition, Kemp (1997) states that firms are 'locked-in' to a technological solution that can be easily adapted to the existing production process. Although this suggests that the most common form of inter-firm relationship would be an arm's length supply relationship, the dynamic, interactive nature of the innovation process suggests the technologies would, at the very least, be customized and modified to fit an existing production process. In addition, there may also be instances where there is a close cooperative relationship between the firms, particularly with the more complex, process-integrated technology. Because these need to be integrated with the user firm's existing production technology, it is possible that a complementary relationship will exist between the firms.

Apart from recognizing the role that policy instruments, and technology types play in the functioning of the innovation system, the model also recognizes that the characteristics of the actors in the system are important too. In particular, the size of the firms involved needs to be addressed, along with the technological strategies of the environmental technology producers. With respect to firm size, the majority of environmental technology firms are small, and as Britton (1990) notes, small firms have a greater difficulty acquiring information necessary for technology development and transfer because of the associated transaction costs. Much of the difficulty that small firms typically experience in developing technology may be offset in the environmental field by the firms acting in the role as specialized suppliers. This may be more pronounced in the case of process-integrated technology where the level of interaction with the regulated firms would be stronger. In this case, both will possess the specialized, even tacit, knowledge about their specific part of the innovation process leading to higher levels of cooperation. Large firms, on the other hand, are better able to internalize the costs of acquiring information, and therefore will not experience the same difficulty as their small competitors in acquiring technological information necessary for the innovation process. Large multi-national firms in particular, are able to obtain information through intra-corporate flows from other plants located elsewhere, in addition to being able to spread the cost more widely.

In addition to recognizing how this model functions with size differences between firms, reference must also be made to the technological strategies of the environmental technology firms. Freeman and Soete (1997) and Rothwell (1992a) state that there are common characteristics. These include: strong in-house professional R&D, close connections with those performing research, use of patents to gain protection and to bargain with competitors, readiness to take high risks, and early imaginative identification of a potential market. Britton and Gilmour (1978) argued that, in the 1970's most firms in Canada could be classified as either dependent or imitative. In taking this position they echo Freeman's (1982) idea that firms can be classified according to their innovation strategies. These strategies are as follows: traditional, dependent, imitative, offensive, defensive, and niche. Traditional firms do not conduct any R&D, their technology being based on craft skills. Dependent firms also conduct little or no internal R&D. Instead, they are dependent on other stronger firms to supply technology, and institute technological changes. The imitative firm has some R&D capability that is directed towards the adaptation of the technologies of more successful firms. Their R&D strategy centers around design and engineering rather than basic research. The defensive firms are 'technological followers' preferring not to take the heavy risks associated with being first to market with a technology. Offensive firms have a strong R&D capability that is focused on bringing new technologies to market. They are highly research intensive, with considerable in-house R&D, and engaging in heavy patent protection. Niche, or opportunist firms, are active in markets that lack many competitors. They are quite innovative and can react quickly to changes in the market.

Porter (1991) also argues that Canadian firms have tended to follow a 'me-too' approach to innovation, acting as technological followers rather than leaders. Although there are examples from a number of different sectors of firms developing advanced technologies, most Canadian firms remain dependent or imitative. While many environmental technology firms are producing in niche markets, little else is known of their innovative capability.

3.4 Chapter Summary

This chapter has examined the usefulness of existing theoretical approaches to explain the environmental regulation-innovation dynamic. In particular, it has assessed the contributions of Michael Porter and Nicholas Ashford. Although their models illustrate, in a simplistic fashion, the plausibility and possible nature of this relationship, they fail to adequately consider the dynamic, complex nature of the innovation process. Furthermore, they suffer from a lack of solid empirical testing. To address this theoretical and empirical shortfall, an alternative model is proposed. Here, environmental regulation exists within a broader system of innovation. In particular, the model identifies the need to consider the process of innovation at the level of the firm, especially the nature of the relationship between the producers of technology and their customers. Consequently, in this revised model, I have argued that the relationship between environmental regulation and technology development can only be understood with reference to the innovation process that underpins the actions of the technology producers.

Chapter 4: From Model to Methodology

4.0 Supporting a 'Regional' Approach to the Research.

Although the previous chapter has detailed the structure of a model with which to understand the relationship between environmental regulation and the development of environmental technology, it needs to be placed within a spatial context in order for it to have any meaning. While the model identifies relationships that may exist between environmental regulation, the environmental technology firm and the regulated firm, these relationships exist within specific and institutional contexts. The connections for example, between the environmental technology firm and the regulated firm can take place at a number of different spatial scales: local; national; or even international. So the question emerges then for the purpose of this enquiry, what is the most appropriate scale to test the environmental-innovation model? Porter (1990), though aware of the regional nature of inter-firm relations, seems to have approached the issue at the national scale, given the national scope of his anecdotal evidence. Although Ashford (1993) supports his model with examples drawn largely from US federal legislation, he provides no other, more explicit, indication of the appropriate scale. Consequently, these existing models provide no explicit locational specification of the linkage between environmental regulation and technology development.

The environmental-innovation model proposed in chapter 3 is conceived to apply at the regional scale. The WWT industry in Canada is regionally concentrated with over 60% of the industry located in Ontario. This localization therefore, supports a regional approach to the enquiry on the supply side. While this is a practical answer to the question of the scale of the enquiry, support for this approach is also drawn from a number of other sources that have theorized about regional industrial development.

Theoretically, innovation theory suggests this form of localization may be the outcome of a variety of factors. Of particular importance is the 'Regional Innovation System' which has emerged recently as a source of inquiry for geographers, economists and political scientists (Cooke and Morgan 1994, Amin and Thrift 1995, Storper 1995, Morgan 1997, Pratt 1997, Wiig and Wood 1997, Maskell and Malmberg 1997). This interest in regionally based technological change has developed out of a much broader inquiry into the organization and re-organization of industrial capitalism in the late twentieth century (Gertler 1988,1992, Hudson 1989, Storper and Walker 1989, Amin and Robins 1990). This re-organization has seen the continued evolution of more flexible forms of manufacturing, out of a previously dominant system of 'Fordist' mass production (Piore and Sabel 1984, Roobeek 1987, Sayer and Walker 1992, Amin 1994). While the nature of this 'flexibility' is the subject of much debate within economic geography (as well as well as other disciplines), there is recognition of the importance of regional systems of industrial organization (Sabel 1989, Schoenberger 1989, Scott 1988, Saxenian 1994, Storper 1994, Storper and Harrison 1991, Scott and Storper 1995). These regionally identified production systems have emerged despite the pressures of globalization (Storper 1992, 1995, Cooke and Morgan 1998).

A key facet of the emergence of flexible production systems is the creation of strong linkages between interdependent producers, who have converged to create spatially clustered production complexes (Scott 1988, 1992. Scott and Storper 1992, Storper and Walker 1989). These regional agglomerations of firms provide an environment for close interaction that facilitates the creation and dissemination of knowledge, necessary for the process of innovation. Storper (1992) suggests that the density of interfirm relationships and the frequency of interaction influences the level of innovativeness of these production complexes. As technological change proceeds, uncertainty and risk also increase because the technology is relatively untried. There is an element of risk associated with all innovative technology, especially the threat of being locked into a technologically inferior product. The new technologies do not have the dynamic learning effects from which the existing technological trajectory has benefited. The uncertainty associated with the adoption of untried innovative technology can be diminished by improving the knowledge base of the firm. Information and knowledge exchanges, especially in terms of uncodifiable tacit knowledge, would lead to the elimination of risk and uncertainty, a factor that is easier when firms are in close proximity. Locational proximity between firms may increase interaction between users and producers, which in turn generates trust and further collaboration (Sabel, Herrigel, Kazis, and Deeg 1987, Lundvall 1992, Harrison 1992).

Porter (1990) maintains that the competitive advantage of nations is embedded in the region. He says that "The process of creating true competitive advantage is localized and benefits greatly from the proximity of lead customers, suppliers, educational institutions and rivals". The role of these institutions has been recognized as being important factors in the success of Emilia Romagna (Brusco 1986) and Baden -Wurttemberg (Cooke and Morgan 1993, Heidenreich and Krauss 1998).

In making a more general argument, Gertler (1993, 1994, 1997) argues that the level of personal interaction between producers and users is in part a function of distance. As distance between firms increases, the level of personal interaction declines. Gertler also notes that culture, which includes a set of institutions, industrial practices and social relations of production, is an important factor in the transfer of knowledge concerning technology. This is especially the case when the producers of technology are located offshore from the users.

While practical reasons exist to support the enquiry at the regional scale, support can also be drawn from the theoretical literature, too. Therefore, a methodology has been developed to support the enquiry at two levels. Firstly, to prove that the hypothesized relationships, as described in the model proposed in chapter 3 exist, and secondly, to test the regional specificity of the model.

4.1 Determination of the Population of Firms for the Study

The methodology employed in this research involves the collection of primary data on the organization and innovation strategies of the water and wastewater technology industry. The collection of these data was extremely important as existing studies of the environmental technology industry failed to disaggregate data in terms of industry sub-sector. Therefore, no comprehensive data existed on the organization and innovation strategies of the WWT sector alone. In addition, Industry Canada has not defined environmental technology let alone the WWT sub-sector, as an individual industrial sector. The principal reason for this is that many of the activities carried out by this industry, are already, or more easily classified under existing industrial classification schemes such as SIC or Standard Industrial Classification codes. This hinders the availability of comprehensive data on its activities. Industry Canada subsumes this activity under SIC 3199 which is Other Machinery and Equipment Industries, not elsewhere classified. Under this classification code many different types of machinery are included, especially environmental technology, chainsaws, cooking equipment, wheelbarrows and lawnmowers.

The best estimate available of the structure of the environmental technology industry comes from consulting reports written for and by both the Federal and Provincial governments especially Ernst and Young (1992), Fouillard (1994), Industry Canada (1994), and Environment Canada (1995). While these provide some useful background on the industry's activities, they were quite insufficient for analyses of the type of technology developed, the role of environmental regulation as an innovation stimulus, and the characteristics of the producer-user relationship. Consequently, the collection of primary data was a methodological necessity.

Because the environmental technology industry is not officially recognised as an independent industrial sector under the SIC coding system of Statistics Canada, the task of determining the population of manufacturers of water pollution control and prevention technologies was not an easy one. Scott's industrial directories, which use US industry codes provide no more assistance. Ernst and Young (1992), however, and Industry Canada (1993) provided the first working directories, establishing that the number of firms manufacturing all categories of environmental technologies nationally, totals approximately 1800 firms. There is an additional 3000 service firms. Later work by the Canadian Environmental Industry Association (CEIA), Ontario chapter (1995) and the publication of the Canadian Environmental Directory (1995) identified a much smaller number of environmental manufacturing firms, service companies and consultants (3900 in Canada). They use a more rigid definition of an environmental firm than Ernst and Young and Industry Canada, who cast a very broad net including firms whose core area of business is not necessarily the provision of environmental technologies or services. Therefore, their total includes firms that may manufacture a filter or a pipe which could have many different applications, including pollution control (end-of-pipe) and pollution prevention (process-integrated). The common denominator for these firms is "their activities are generated by purchasers' efforts to clean-up or prevent damage to the environment." (Ernst and Young 1992).

The CEIA membership directory (1995) and the Canadian Environmental Directory (1995) take a more focused view of the industry. Their lists incorporate manufacturers of environmental technologies and those offering environmental consultative and engineering services. Consequently, their lists are smaller, though CEIA includes government organizations, university laboratories, and public utilities in their membership list too.

Approximately 20% of the 2000 firms listed by CEIA (1995) and the Canadian Environmental Directory (1995) located in Ontario, manufacture environmental technologies, or provide engineering services associated with those technologies. The remaining 80% of firms provide a wide range of services including legal, consultative, site remediation, and waste management. Therefore, using these sampling frames, the Ontario population of manufacturers of environmental technologies was initially determined to be approximately 400 firms. This population was further stratified further according to the medium of pollution the technologies were designed to address, thus allowing the population of water and wastewater technology firms to be identified. The stratification was established using Ernst and Young (1992), and the Canadian Environmental Directory (1995) and subsequently modified through communication with CEIA and the Ontario Center for Environmental Technology Advancement (OCETA). Of the 400 environmentai technology producers, approximately 33% or 130 firms manufacture water and wastewater technology. Therefore, for the purposes of this research, the population of Ontario firms was deemed to be 130.

The research targeted water and wastewater technology firms because, as shown in Chapter 1, this is the largest sub-sector of a larger environmental technology industry, and the firms are spatially concentrated in Ontario. More importantly, the innovation process could only be modeled by focusing specifically on one set of environmental regulations. Expanding the population of firms to include air pollution and waste management, for example, would have involved two additional sets of regulations, with two additional sets of expectations. While the 'Approvals' process is common to both of these other sub-sectors, there is no equivalent of the MISA programme. Therefore, the same range of technological outcomes in response to the particulars of the regulation could not be expected. This would make it very difficult to compare results across industry sub-sectors.

In order to test the environmental-innovation model, the Ontario population of water and wastewater technology manufacturers was surveyed using two survey instruments. A mail-out questionnaire was administered to the complete population in the first phase of the research. The second phase consisted of a series of follow-up interviews with a subset of the respondents to the initial mail-out questionnaire. In addition, interviews were conducted with a selection of firms who are subject to environmental regulation, and with representatives of government. The relatively small size of the population allowed all firms to be contacted.

To identify the name of a contact person within the population to be surveyed, each firm was telephoned. This process also had the goal of establishing a commitment on the part of the respondent to take part in the survey. This was an important first step as it has been demonstrated that an initial telephone call to potential respondents may improve the response rate to the survey (Hanson et al 1983). Although the Canadian Environmental Directory contained the name and address of a contact for each firm, it was discovered that in many instances, this information was incorrect. There were examples of the contact person having left the firm a number of years previously, being moved to another branch, or in one case, the firm had not been at the listed location for a number of years. So, the initial telephone also served to update the contact information on each firm. Of the 130 firms initially thought to be the population of water and wastewater technology firms, 40 were removed from the list as they turned out to be distributors only, service firms with no manufacturing function, or were no longer in business. The incorrect listings of both the contact person and the firm's activities by the Canadian Environmental Directory resulted in a greater amount of time being spent on the verification of this information than was originally intended. This was extremely frustrating given that this directory is the only comprehensive list available of firms in the environmental sector in Canada. However, this extra time investment was necessary because as Alreck and Settle (1985) note, the response rate to mail-out surveys is very low, sometimes less than 30%. Therefore, ensuring that firm information is as up to date as possible before mailing will help secure as high a response rate as possible. The population of firms the survey was, in the end, determined to be 90 firms.[1] Of these, 10 refused to participate in the survey. The principal reason given was the lack of time, although 3 of these firms also indicated that they didn't consider themselves as environmental technology firms. These firms were still included in the population figure as they were described in the Canadian Environmental Directory (1995) as being environmental firms. The remaining 80 firms agreed to receive the questionnaire, although no firm guarantee was given that the survey would be actually filled out.

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[1] Many interview participants even believe this figure to be overstated. They believe instead that the

4.2 Phase 1: Survey Questionnaire

4.2.1 Pre Tests

Prior to administering the mail-out survey, the questionnaire was pre tested with a selected number of firms. In addition, representatives of the Canadian Environmental Industry Association, and OCETA evaluated the questionnaire as knowledgeable informants of the Ontario environmental technology industry. The purpose of these pre-tests was to determine if the questionnaire was an effective and comprehensible tool to gather the information necessary for the research. The principal criticism made of the questionnaire concerned its length. However, it was impossible to reduce the size of the questionnaire without the possibility of excluding key information, consequently, the changes that were made concerned the clarity in order to improve the ease of respondents in understanding of the questions. Once these pre-tests were completed in June 1996, the final questionnaire was mailed out to the population of firms during July and August 1996. In addition to the questionnaire, the respondents were provided with a covering letter informing them of the purpose of the research and a self-addressed stamped envelope, to help improve the response rate. The covering letter also guaranteed the anonymity and confidentially of the responses. The questionnaire and the covering letter are contained in Appendix 4.

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number of firms who manufacture water pollution control and prevention technologies as their core

4.2.2 Response Rate

Of the 80 firms sent the questionnaire, only ten sent it back after three weeks, including one firm who said that the information asked was of a proprietary nature and as a result could not take part in the survey. After the first round of follow up telephone calls, it was discovered that many of the potential respondents were in fact, on vacation, hence the rather low initial response rate. In a number of cases, the questionnaire had become lost under the backlog of mail the respondent had accumulated while away,. This necessitated the resending of another 35 questionnaires. In many cases, the firms were actually sent three copies of the questionnaire, despite having received an initial undertaking from the potential respondent that it would be filled out. As a result of these resends and another two series of follow up calls, the number of responses received tapered off at 36 by the end of October 1996. The response rate for the first phase survey instrument was, therefore, approximately 45%. Although this may appear low, it is not unusual for industrial surveys of this type[2]. In addition, the Ontario Center for Environmental Technology Advancement administered a substantially shorter questionnaire to over 300 environmental firms in the Kitchener/Waterloo region, at the same time as this survey.[3] Despite a larger budget (even employing a professional statistician), they had a response rate of approximately 26%, with only one question receiving the overall response rate. The response rate for their remaining

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business activity probably numbers less than 50.

[2] de Vet and Scott's (1992) mail-out survey of the medical device industry in Southern California yielded a 16.7% response rate. Similarly, Labatt's (1994) study of the reaction of Canadian firms to the National Packaging Protocol, realized a 49.5% response rate to the survey instrument.

[3] The questions in the OCETA survey attempted to gather information on each firm's current employment and sales, and their projections for these variables in the future. For further information regarding this survey please see OCETA (1996) Environmental Business in the Canadian Technology Triangle, unpublished survey results.

questions varied between 10% and 21%.

The comparison of response rate according to establishment size is presented in Table 4.1, while the comparison of response rates according to firm ownership is presented in Table 4.2.

Table 4.1 Comparison of Response Rate, by Establishment Size.

SIZE CATEGORY	NUMBER OF EMPLOYEES	TOTAL FIRMS	NUMBER OF RESPONSES	RESPONSE RATE BY SIZE
Small	1-50	61	29	47.5 %
Large	>50	19	7	36.8 %
TOTAL		**80**	**36**	**45%**

Table 4.2 Comparison of Response Rate, by Firm Ownership.

OWNERSHIP CATEGORY	TOTAL FIRMS	NUMBER OF RESPONSES	RESPONSE RATE BY OWNERSHIP
Canadian	62	27	43.5 %
Foreign	18	9	50 %
TOTAL	**80**	**36**	**45%**

4.2.3 Non Response Bias

Although the number of responses to this survey was sufficient to allow the data to be analyzed in a meaningful way, a feature of any mail-out survey is the possible bias that may exist due to non response. Therefore, it was necessary to investigate the reasons for non response by firms, and to determine if this would influence the final results. The principal reason given by firms for not replying to the survey was the lack of time. While firms indicated they would look at this survey, they could not guarantee that they would fill it out. In particular, many firms indicated that they tended to rank the surveys received, giving higher preference to those they were obligated to respond to, for example, Statistics Canada surveys. In addition, a small number of firms indicated that they could not answer the questionnaire because it would mean parting with information they deemed to be of a sensitive nature.

In order to evaluate the representativeness of the survey, Chi-square tests were conducted on the firm characteristics of size and ownership. Size was categorized as either a small and medium sized firm, or a large firm, and ownership was categorized as either Canadian, or foreign. The results of these tests can be found in Appendix 4, but in summary, they indicated that no significant difference existed between respondents and non-respondents with respect to these characteristics. Therefore, these results suggest that non-response bias as measured by firm size and firm ownership, appears not to be a significant problem in this survey.

4.3 Characteristics of the Water and Wastewater Technology Sub-Sector

The data on the organizational characteristics of the Water and Wastewater Technology (WWT) sector, obtained from the mail-out questionnaire and presented here, establish a context in which to place the analyses of the following chapters. The characteristics presented in this section include the size distribution of firms, their ownership structure, and their product orientation.

4.3.1 Firm Characteristics

The surveyed firms were asked to provide information on a number of different organizational and performance characteristics. In most cases, this information was provided without question. However, in a number of cases, the respondent firms deemed this information to be of a proprietary nature, particularly with respect to sales information and export orientation, and did not provide it.

As indicated in Chapter 3, the innovation strategies of the respondent firms might be associated with the characteristics such as firm size and firm ownership. Although the response rate for the survey was reasonable for an industrial survey, the actual number of cases (36 firms) was too low to conduct multivariate statistical analysis of the firm's organizational and innovation characteristics. Instead, a number of bivariate Chi-square contingency tests were conducted to discover if any statistical relationships existed between key variables.

In each evaluation of the relationships between firm size and ownership, ownership and function, and ownership and pollution orientation, the small sample size required a modified Chi-Square, Fisher's Exact Test, to be used so that exact rather than approximate probabilities could be observed (Blalock 1979). This has the advantage of being, in the case of a 2x2 contingency table, an alternative for the continuity correction (Walker and Lev 1953, Blalock 1979). Nevertheless, the results of these Chi-square tests should still be viewed as indicative rather than conclusive due to the small number of cases. The frequency distributions of the firm's characteristics are presented in Table 4.3.

Table 4.3: Summary Frequency Tables of Firm Characteristics by Respondents

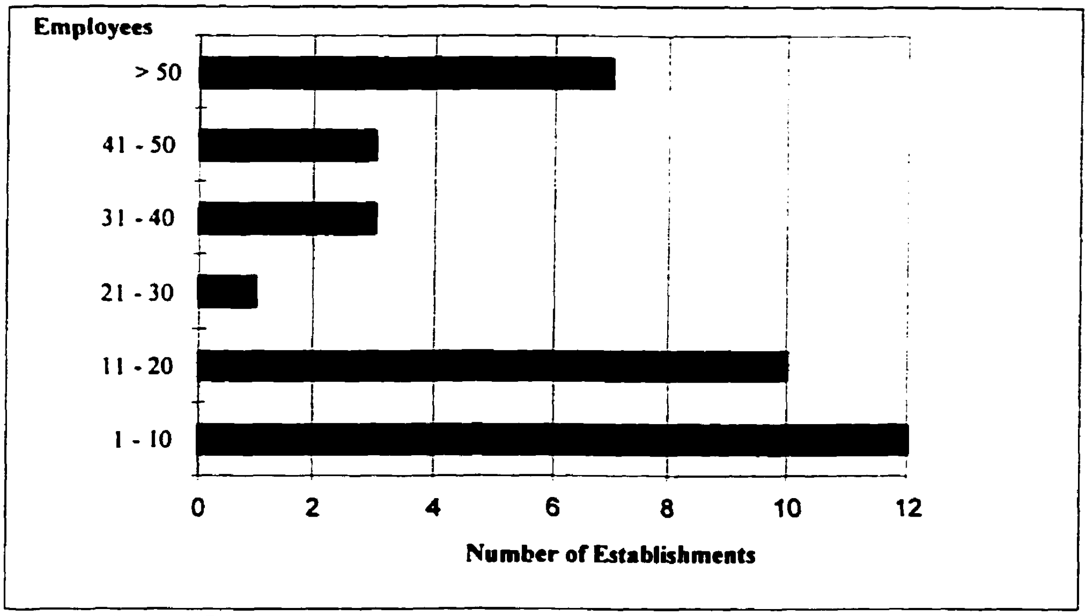
FIRM CHARACTERISTIC	FREQUENCY	% OF RESPONSES
Establishment Size (n=36)		
Small (1-50 Employees)	29	81 %
Large (>50 Employees)	7	19 %
Ownership (n=36)		
Canadian	27	75 %
Foreign Subsidiary	9	25 %
Function (n=36)		
Manufacturer	25	69 %
Manufacturer/Technical Services	11	31 %
Pollution Orientation (n=36)		
Water only	17	47 %
Multi Media	19	53 %
Technology Orientation (n=36)		
End-of-Pipe	18	50 %
Process-integrated	13	36 %
End-of-Pipe + Process-integrated	5	14 %

Source: Survey Data

4.3.2 Establishment Size

Approximately 81% of the respondent establishments have 50 employees or less, and are deemed to be small sized establishments. The remaining 7 establishments (19%) would normally be viewed as medium or large, although there is quite a variation in size among this group from 80 employees up to 1300 employees (Figure 4.1).

Figure 4.1: Distribution of Respondents by Establishment Size (Employees).



Source: Survey Data

Although the total number of employees is commonly used as a method of classifying establishments by size, there is no one absolute measure which determines the threshold between a small establishment and a medium or large establishment. The OECD (1993), which has defined a commonly used benchmark, classifies small establishments as less than 100 employees, and large establishments as greater than 500. While Ettlinger and Tufford (1996), and Britton (1996) also use this classification, other studies define small establishments as employing less than 20 (Rees, Briggs, and Oakey 1984, Ray 1996). Therefore, there are a variety of interpretations as to what can constitute a small establishment. In the WWT sector, 81% of establishments employ less than 50 employees, while 33% of establishments employ 10 or fewer. This indicates that the WWT sector is structured around a proportionally large number of very small establishments, and as a result, it is difficult to use the traditional measures that have been applied to other sectors. To arbitrarily use the 100 employee threshold as is common in other studies, would fail to capture the fact that many of the establishments in this industry are very small. It should be noted however, that some small respondent establishments are the branch plants of multilocational firms and as a result would benefit from being incorporated into a much larger organizational structure

4.3.3 Firm Ownership

Firm ownership was classified as two types: Canadian owned, meaning either 100% Canadian ownership, or the majority owner being Canadian, and Foreign Subsidiaries meaning the Canadian branch plant of a foreign-owned firm. It was important to classify the firms in this way as one of the goals of this research was to establish if foreign-owned firms were reacting to the local Canadian policy regime or if their 'home' regulations were embedded in the technologies they manufactured.

Of the 36 respondents to the survey, 27 (75%) were Canadian owned establishments, while the remaining 9 establishments (25%) were the branch plants of foreign-owned firms. Of the Canadian owned firms, all but one were 100% Canadian, while the remaining one firm was 80% Canadian and 20% Dutch owned. With respect to the foreign branch plants, all but one were US owned, while the headquarters of the remaining firm is located in England.

These ownership figures appear to compare favorably with the ownership rates for manufacturing in Canada as a whole. Both Porter (1991) and MacPherson (1996) have indicated that foreign control of manufacturing firms in Canada is between 40 - 50%. Therefore, it appears that there is a strong Canadian presence in this industry.

With respect to the ownership structure of the WWT sector, 76% of small establishments are Canadian owned compared with 24% that are Foreign subsidiaries. Of the large establishments, just under 71% are Canadian owned while just over 28% are Foreign-owned branch plants (Table 4.4).

Table 4.4: Distribution of Respondents by Establishment Size and Ownership

	SMALL (<50 EMPLOYEES)	LARGE (>50 EMPLOYEES)	TOTAL
Canadian Single	20	0	20
Canadian Branch	2	5	7
Foreign Subsidiary	7	2	9
TOTAL	29	7	36

Source: Survey Data

The results of the Chi-square test indicate that the relationship between establishment size and ownership is not significant (Table 4.5). This implies that although the majority of establishments in the WWT sector are small and Canadian owned, it is not the case that larger establishments are more likely to be foreign-owned. In fact, as Table 4.4 indicates, five of the seven largest establishments that replied to the survey are actually Canadian owned. While this appears to indicate that, on the basis of size, Canadian owned establishments are not at a disadvantage, as noted above, the small sized foreign-owned establishments are in fact, able to benefit from being parts of much larger organizational structures.

Table 4.5: The Relationship between Establishment Size and Ownership

Count (Row pct) (Col. Pct)	**Canadian**	**Foreign**	Row Total
Small	**22** (75.8) (81.4)	**7** (24.2) (77.7)	**29** (80.6)
Large	**5** (71.4) (19.2)	**2** (28.6) (22.2)	**7** (19.4)
Column Total	**26** (75.0)	**10** (25.0)	**36** (100)

Chi-Sq .= .00273	DF = 1	p (Fisher's) = .645

4.3.4. Pollution Orientation

The firms[4] were asked, in the survey, to indicate the percentage of their output that was manufactured to address a particular pollution medium. The pollution media listed were water and wastewater, air, and waste management. These data were then converted to categorical data for ease of comparison, and then generalized to two groups: water and wastewater, and multi-media. The multi-media category reflected any combination of water and wastewater and one or more of the remaining media, while water and wastewater referred to orientation towards that medium to the exclusion of the others. The purpose of dividing the firms in this manner was to try and discover the degree of specialization of firms in the

[4] For this, and subsequent, analysis(es), the term 'firm' is used instead of establishment, to refer to the legal form of the basic producing unit. Thus a small firm consists of a single establishment of less than 50 employees. A large firm is a multilocational organization consisting of large and small establishments, or a single establishment of greater than 50 employees. The distribution of large and small firms in this research is presented in Table 4c, Appendix 4.

manufacture of water and wastewater technologies or if there was an identifiable overlap with other pollution media. This could have important implications from a policy analysis perspective given the difference between water pollution regulation and air or waste management regulation, and the possible influence these separate policy regimes could have on the innovation strategy of individual firms.

Of the firms who replied to the survey, 17 (47%) indicated that they manufactured water and wastewater technology only, while the remaining 19 firms (53%) were multi-media firms. A breakdown of the responses by non-aggregated pollution medium is given in Table 4.6.

Table 4.6 Distribution of Firms by Pollution Orientation

POLLUTION MEDIUM	NO. OF RESPONSES	% OF RESPONDENTS
Water only (water and wastewater)	17	47 %
Water + Air	1	3 %
Water + Waste Management	9	25 %
Water + Air + Waste Management	9	25 %
Total	**36**	**100 %**

Source: Survey Data

4.3.5 Firm Function

Some firms are solely manufacturers of technology, while others also provide a technical service function. In this survey, 25 (69%) of firms indicated that their sole function was that of a manufacturer of technology. The remaining 11 firms (31%) indicated that in addition to manufacturing, they also provided scientific and technical services to customers. On average, 19% of the economic activity of the average firm in this group of 11 firms, was devoted to providing technical services. The actual values range from 2% up to 50% and interviews revealed were provided to a different set of customers from those who actually bought technologies.

4.3.6 Technology Type

Firms have been classified into three groups depending on their manufacture of end-of-pipe technologies, process-integrated technologies, or both. The classification is possible because the firms were asked to report on up to three of their technologies, and this yielded a good indication of their technology orientation.

There appears to be a specialization towards the manufacture of end-of-pipe technology among the sample firms with 18 (50%) indicating that they only manufacture end-of-pipe technologies. This is followed by 13 firms (36%) who manufacture process-integrated technologies only, and 5 firms (14%) manufacture both end-of-pipe and process-integrated technologies.

4.3.7 Firm Size and Function

Analysis of the data from the questionnaire reveals that there is no statistically significant relationship between small firms and large firms with respect to the function of the firm (Table 4.7). Of the 25 firms who describe themselves as manufacturers only, 44% are small firms while the remaining 56% are large firms. The split between large and small firms is reversed in the case of firms who in addition to manufacturing, provide technical services (approximately 73% are small firms and approximately 27% are large firms). This result suggests that small firms in the WWT sector are flexible in their ability to carry out a variety of tasks associated with the development and manufacture of water and wastewater technology. In addition, large firms are no more likely to diversify their organizational structure towards the provision of a service function in addition to manufacturing.

Table 4.7: The Relationship between Firm Size and Function

Count (Row pct) (Col. Pct)	**Small**	**Large**	Row Total
Manufacturer	**11** (44.0) (57.9)	**14** (56.0) (82.4)	**25** (69.4)
Manufacturer + Technical Services	**8** (72.7) (42.1)	**3** (27.3) (17.6)	**11** (30.6)
Column Total	**19** (52.8)	**17** (47.2)	**36** (100)

Chi-Sq .= 2.529	DF = 1	p (Fisher's)= .109

4.3.8 Firm Size and Pollution Orientation

The relationship between firm size and the focus of the firm on producing for a range a range of pollution media is also not statistically significant (Table 4.8). Of the firms whose sole focus is water and wastewater technology, approximately 41% are small firms while the remaining 58% are large. However, with respect to multi-media firms, over 63% are small firms while only 7 firms (36%) are large. This is an interesting result, and one which will be probed further in chapter 6, however, at the outset it does appear to indicate a certain degree of flexibility on the part of small firms in their ability to operate in more than one technology market. It also indicates a slight degree of concentration of small firm activity in the multi-media category.

Table 4.8: The Relationship between Firm Size and Pollution Orientation

Count (Row pct) (Col Pct)	Small	Large	Row Total
Water only	**7** (41.2) (36.8)	**10** (58.8) (58.8)	**17** (47.2)
Multi-Media	**12** (63.2) (63.2)	**7** (36.8) (41.2)	**19** (52.8)
Column Total	**19** (52.8)	**17** (47.2)	**36** (100)

Chi-Sq .= 1.739	DF = 1	p (Fisher's)= .163

These simple bivariate tests indicate is that firm size and ownership, function, and pollution orientation, are unrelated in Ontario. Small firms are as likely to provide a variety of manufacturing and related activities, and to operate in more than one technology market, as large firms are. This is interesting as it implies that small firms are sufficiently resourceful to be competitive across the market for water and wastewater technologies. These issues will be probed further in the coming chapters.

4.4 Survey Instruments

4.4.1 Structure of the Questionnaire

The questionnaire was designed to obtain data in six key areas, the organizational structure of the firms, their performance characteristics, their principal technologies, their knowledge of environmental regulation, the characteristics of their innovation process, and the character of their external linkages. The six key areas reflected the need to not only establish the existence of the linkages between the four components of the environmental-innovation model (regulations, WWT firms, regulated firms, and technologies), but to also provide crucial information on the structure and organization of the WWT industry.

The first three sections of the questionnaire (A, B. and C, see Appendix 4) provide the information on the structure and organization of the WWT industry. It was important to collect this information because as mentioned above, existing studies have failed to provide enough depth on the industry. For the model to be a true representation of the relationship between environmental regulation and the development of environmental technology, it needs to be applicable to the different structural components of the WWT industry including small and large firms, and foreign and domestic firms. Through sections A, B, and C, the questionnaire allows a means for interpreting the characteristics of the environmental-innovation model.

The remainder of the questionnaire (sections D, E, and F) allows the linkages between the components of the environmental-innovation model to be described. In particular, it permits analysis of the role of environmental regulations in directing the innovation process. In addition, information has been collected on the relationship between WWT firms and their customers (the regulated firms).

(A). Organizational Characteristics (questions 1, 2, 19, 20, 21, 22, 23, 23a, 32, 33)

These questions gather structural and ownership information on the firms. And extend considerably the information available from reports presenting only an aggregated picture of the industry without reference to industry sub-sectors.[5] It was planned to compare the choices and experiences of the respondent firms with a number of organizational variables, for example, size and ownership. These two variables are of particular relevance since a number of consulting and government reports indicate the predominance of small firms in the environmental sector in Canada (Ernst and Young 1992, Industry Canada 1994). It is important, therefore, to understand the innovative practices of these smaller firms compared with those of large firms. On the one hand, the small WWT firms might be expected to produce the more standardized end-of-pipe technologies rather than the more technologically advanced process-integrated technologies. This results from the higher transaction costs they typically face in the acquisition of information necessary for technology development and transfer. On the other, it is also possible that some small firms may specialize in the customization of one particular process-integrated technology (see Section 3.3.1, Chapter 3). Given the high penetration of foreign-owned firms in the Canadian economy, it is also important to understand the innovative practices of these foreign firms compared to domestically owned firms. This is especially the case when evaluating the contribution that domestic environmental regulations have on their activities. Typically, foreign-owned firms will engage in intracorporate transfers of technology from their parent location leading to a truncation of their innovation process in the host country (Britton and Gilmour 1978).

[5] See Ernst and Young (1992), Fouillard (1992), Industry Canada (1994)

Consequently, the foreign-owned WWT firms would be expected to manufacture technologies that have been developed in their parent location in response to the regulatory system there, and distributed in an off-the-shelf fashion. In addition, given the dominance of technology-based approaches to regulation in their parent locations, they would be expected to produce end-of-pipe technology as opposed to process-integrated technology.

(B). Performance Characteristics (questions 18, 24, 26, 27, 29, 30, 31)

These questions were designed to gather information on each firm's production and competitiveness. Measures such as export intensity (question 30), and sales (question 29) can be used as proxy indicators of a firm's or industry's competitiveness (McFetridge 1995). Changes in the value of a firm's or industry's sales (expressed as an index to control for inflation) can be tracked over a period of time to indicate how manufacturing sales revenues have changed. An increase (decrease) in the value of sales will indicate an improvement (decline) in competitiveness. Likewise, an increase in export intensity will indicate an improvement in the firm's or industry's share of the international market for their output. These questions also indicate the how the production activity in the firm is organized (question 18). This can be an important indicator of the firm's ability to react to competitive pressures. Firms manufacturing custom products or products in short batch runs would be able to react to changes in demand faster than those firms which rely on long production runs. The process-integrated technology would be expected to be manufactured in this fashion as it is the least standardized approach to compliance technology. The end-of-pipe technology, being more standardized, would be positioned at the end of the product cycle, and as a result would tend to be manufactured in long production runs.

(C). Technologies (questions 3, 4)

One of the key questions in this research was to establish if the technological strategies of the WWT firms were in any way related to the technology they were developing and manufacturing.

Firms were asked to list the three most important technologies they manufacture (question 3). The term 'most important' was defined as the technology with the highest sales value. In addition, the firms were also asked to indicate the technology used in their product for example, ultra-violet radiation, or membrane technology. This was necessary, as one of the research questions was to establish if niche markets existed and if so, how these markets were organized? Knowing the product's technology means that the existence of technology-based niche markets could be established. Freeman and Soete (1997) classify firms that are able to operate within such markets as niche or opportunist in terms of their technological strategy. They are quite innovative, can react quickly to changes in the market, and a result, the achievement of economics of scale is not crucial for their success. The small WWT firms who exploited these niche markets would thus be expected to be able to overcome their size disadvantage and compete successfully.

In question 4, firms were asked to classify their technologies according to their function as end-of-pipe technologies or process-integrated technologies. This information was needed to determine if the actions of the firms were associated with the type of technology they were manufacturing.

(D). Knowledge of Environmental Regulation (questions 6, 7, 8, 23b, 25)

In order to assess the existence of a direct link between environmental regulation and the decision to develop and manufacture the end-of-pipe and process-integrated technologies, it was necessary to determine the firm's actual awareness of regulations.

While question 5 addressed the key motivational forces acting upon the firms, it was important to understand how much the firms actually knew about the regulations. Therefore, it was necessary to ask them about which regulation(s) in particular influenced their decision, and where they acquired the technical details of the regulation (questions 6,7,8).

In other questions (23b, 25) firms were asked how aware they were of the influence on their activities of environmental regulations in other jurisdictions. Firms who indicated they had manufacturing plants abroad were asked in Question 23b if they modified their technologies to suit these local requirements, and in Question 25, firms replied if the technologies that were exported were modified in recognition of the environmental regulations in those export markets.

Porter (1990) and Ashford (1994) both argue that environmental regulations play a crucial role in the development of environmental technology. Porter, in particular, states that it is local policy circumstances that are important and they help drive the competitive development of the domestic environmental technology industry. In addition, Morgan (1997) Storper (1994) and Cooke and Morgan (1994) among others argue that regional institutions (of which environmental regulation is an example) are important determinants of innovative success in firms. These two points taken together would suggest that not only will environmental regulation influence the development of environmental technology, but that local policy circumstances will shape the direction of this innovative activity, such that it will determine the type of technology manufactured. Given the importance of environmental regulations to the innovation process, they also suggest that the regulatory agency will provide firms with the technical requirements of the regulations, further strengthening the expectation of a direct linkage between from the regulations to the WWT firms.

(E). Characteristics of the Innovation Process (questions 5, 9, 10, 13, 14, 15)

The purpose of these questions was to establish the key motivational forces influencing the decision to develop and manufacture the firm's technologies. In addition, the questions established the actual organization of the innovation process. It was hoped that at the minimum, this would allow the technology producers to be classified according to their ability to innovate.

The motivational influences on the firm's decision to develop and manufacture each of their technologies were requested in Question 5. This would, at the outset, provide some explicit data on the degree to which environmental regulation acted as a motivational force. In addition, the role that the customer played and the identification of a market need were singled out as being two other key motivational forces. By asking the firm to rank their responses, the strength of each motivator could be assessed.

A series of questions (Questions 9, 10, 13, 14, 15) was used to determine the innovative ability of the respondent firms. By asking the firms to state their R&D expenditures, as well as the structure of their R&D, a better understanding of the innovativeness of the firms was sought and comparisons of firms in this sub-sector could be made with firms in other high technology sectors in Ontario.

(F). Characteristics of External Linkages (questions 11, 12, 16, 17, 28)

One of the fundamental questions guiding this research was the degree to which technology producers interacted with or collaborated with the users of their technology. As a result, it was necessary to establish if these relationships existed, and if so what form they took. Of particular importance here, in addition to establishing the role of the user in the innovation process, was to understand the path of regulatory influence. In other words, it was important to determine if there was a direct impact on the supplier by environmental regulations, or if that link was actually mediated through the technology users.

Two questions (Questions 11, and 12) sought to establish at what point in the innovation process co-operation between the supplier and user occurred, and how important this was to the respondent firms. Rothwell (1990, 1992b) argues that flows of information between actors in the innovation process are particularly important in the design and engineering phases of innovation. By asking this question for each technology, it is possible to explore the hypothesis that co-operation is more important in the early phases of the innovation process, particularly for the more innovative process-integrated technologies.

The importance of co-operative activities including joint ventures or strategic alliances, for the innovation process of the respondent firms was probed in Question 16. These activities can allow small R&D intensive firms to gain a foothold in international markets (Ahearn 1993). Consequently, the goal in seeking this information was to establish whether small firms in particular used this approach to access technological markets.

The degree of intensity of the co-operative relationships between the producer and the user of the technology is probed in question 17. A close co-operative relationship between the producer and user of the technology is not only important for the development of technology, but to also ensure the successful implementation of that technology (Lundvall 1988, Von Hippel 1988, Gertler 1993, 1994). Consequently, it was expected that the more innovative firms would have a closer relationship with their customers to the point that the customer relied on them to integrate the technology into their existing production process.

The degree to which the respondent firms used external technical or producer services, and government institutions for their innovation process was explored in Question 28. MacPherson (1988) argues that these external sources of technical skill and information, are particularly important for the innovative success of small firms. Therefore, the more innovative small firms would be expected to successfully exploit these external sources of technical expertise, and information.

4.4.2 Selection of Interviews

The second phase of the research entailed three sets of personal interviews - with the manufacturers of water and wastewater technology, with firms who were subject to water pollution legislation and who are users of the technology, and representatives from government.[6] The manufacturers of the technology were selected from the responses received in the first phase of the research. The actual number of interviews was 15 or 42% of the responses. Within that group, there was representation in terms of the size of firms and their ownership. The criterion used for the selection of the interviewees, within the size and ownership classes was the quality of the information received in the questionnaire, as well as their willingness to participate in this phase of the research.

[6] The results of the interviews appear throughout Chapters 5 and 6.

The interview questions, a copy of which is contained in Appendix 4, were more qualitative in nature. They focused on each firm's innovation strategies particularly their relationships with their customers. This emerged, as a result of the phase 1 questionnaire, as an important part of their innovation strategy, therefore it was necessary to explore it further here, too. The interviews also focused on the role that environmental regulation actually played in their innovation decisions. This information augmented the data collected in the survey as the interviews allowed a much deeper probing of some of the initial responses received. Schoenberger (1991) notes that the corporate interview is the most effective way of understanding a firm's behavior, as the questions asked were usually open-ended allowing room for discussion and the qualification of any ambiguities of information.

In order to better understand the relationship between the manufacturers of water and wastewater technology and their customers, a small number of 'customer' firms who are subject to water pollution legislation were interviewed. These firms, five of them, were identified with the assistance of the technology manufacturers, and are the largest single industrial customers for water and wastewater technology. Though large, they represent a good cross section of Ontario's key manufacturing industries, and are specifically targeted under provincial water pollution legislation. In that regard, they are members of sectors which contribute heavily to Ontario's water pollution problems. The sectors chosen therefore, were Pulp and Paper, Chemicals/Petroleum, and Primary Metals, and the interviewees were either the senior process engineer, or the engineer responsible for environmental compliance. In all cases, the interviewees could be considered to be the 'key informant' for their particular firm (Markusen 1994). The questions asked this group focused on the type of technologies they had employed to achieve compliance, the role that environmental regulations played in their decision to use the particular technology, and their relationship with their supplier of pollution control and prevention technology. A copy of the questionnaire is contained in Appendix 4.

The last group of interviews conducted was with three officers of the provincial Ministry of Environment, representing the Policy Development Branch, Science and Technology Branch, and the Green Industry Office. In all cases, the respondent was a senior official within each department, and as a result was able to provide information of a very high quality. The purpose of these interviews was to understand the process through which water pollution regulations are determined; the existence of direct linkages between the government and the suppliers of technologies in the establishment of regulations; and the role the role the provincial government plays in the development of the water and wastewater technology industry.

4.4 Research Hypotheses

The expectations for the research can be summarized in the following list of research hypotheses:

1. *Regulation will act as a strong motivation for the development and manufacture of water and wastewater technology.*
2. *The type of environmental regulation will influence the type of technology developed and manufactured.* The dominance of design standards will mean more end-of-pipe as opposed to process-integrated technology.
3. *Foreign firms will manufacture technology that has been developed in their home location in response to the regulatory system there.*

4. Because of Hypothesis 3, *foreign-owned firms will produce standardized technologies*. They are more likely to distribute or transfer technology manufactured abroad, in an off-the-shelf fashion. They do not perform R&D within the province, and they do not establish close relationships with the technology users. They don't establish co-operative linkages with domestic water and wastewater technology suppliers.

On the issue of firm size, it is not possible to construct formal hypotheses. Large firms might be expected to be more innovative and as a result, more likely to produce more complex process-integrated technologies. However, if these firms are foreign-owned, under Hypothesis 4, they would be expected to produce end-of-pipe technology. Similarly, small firms might be less innovative and more likely to produce the more standardized end-of-pipe technology. However, it is also possible they customize a single process-integrated technology, and as a result are no less innovative than large firms. Consequently, on the issue of firm size, a variety of outcomes is possible.

5. *Small firms who are able to exploit or use external linkages may overcome their size disadvantage.* Therefore, co-operative innovation strategies between the small manufacturers and the regulated firms, and between small manufacturers and other larger manufacturers (through strategic alliances) are important.
6. *Firms manufacturing more complex process-integrated technologies, will experience a greater level of interaction and co-operation with the users of the technology (regulated firms).* This interaction will be less intense with the manufacturers of standardized pollution control technologies. Co-operation is more important in the early phases of the innovation process, particularly for the more innovative process-integrated technologies.

7. *Locational proximity to regulated firms is an important factor in the successful development of process-integrated technology.* This is less so in the case of end-of-pipe technology.
8. *Public and Private sector institutions are an important element in the innovation strategy of small domestic technology manufacturers.*

4.6 Chapter Summary

This chapter has detailed the methodology employed in this enquiry. In addition, the chapter has presented the structural characteristics of the WWT industry, which will be used to interpret the results of the following chapters.

The enquiry was conducted at the regional scale for two reasons: practicality, due to the concentration of this industry in Ontario; it allows the regional specificity of the model to be tested, and in doing so contributes to the debate surrounding the regional nature of innovation. Primary data were collected using a mail-out survey to the WWT firms and a series of follow up interviews with the WWT firms, a small number of technology users, and representatives from government. This approach to the enquiry was appropriate given the lack of depth that existing studies of this industry in Canada contain.

Chapter 5: Establishing the Basic Parameters of Ontario's Environmental-Innovation Model.

5.0 Introduction

In most advanced economies, innovation systems have evolved to underpin the development of environmental technology, as a result of social and political pressures locally, nationally and internationally. Environmental regulation (see Chapters 2 and 3) is an essential part of this innovation system, stimulating its operation, and is a key component of the environmental-innovation model. There are several channels through which it is plausible that the effects of this regulatory influence can be perceived. On the one hand, firms subject to the regulation may be able to react directly to the new technical requirements, on the other, their compliance may involve sourcing technology externally either off-the shelf, or through some cooperative arrangement with the environmental technology firm.[1] The purpose of this chapter is to not only test the role environmental regulation plays as an innovation stimulus in Ontario, but also to examine the path through which this regulatory stimulus is channeled. Based on data received through the mail-out survey, and supported with interviews, this chapter presents an empirical analysis of the role environmental regulation plays in the development of water and wastewater technology in Ontario. In doing so, it identifies the existence of an innovation process, and further verifies the general outline of the environmental-innovation model proposed in Chapter 3.

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[1] Ernst and Young (1992) estimate that between 70% and 90% of the regulated firms' compliance requirements are sourced externally. Hutcheson, Pearson, and Ball, (1996) argue that chemical firms obtain most of their capital equipment from external sources.

5.1 Factors Influencing the Development of Environmental Technology

Based on the theoretical literature on environmental policy and technological innovation (reviewed in Chapters 2 and 3), three important influences on the development of end-of-pipe and process-integrated technologies can be identified. These are: (a) a direct response to environmental regulation by environmental technology firms; (b) a direct response to the current needs of individual industrial customers; and (c) the environmental technology firms' own perception of a future or prospective market for technology which reflects their expectation about changes in environmental regulation. The influences (a) and (b) can, in fact, be considered regulatory influences. In the case of (a), the environmental technology firm reacts directly to the influence of environmental regulation anticipating demand from regulated or user firms. This is consistent with a direct path of influence from environmental regulation to the environmental technology firm indicated in the environmental-innovation model.

In the case of (b), the regulatory influence is indirect because the environmental technology firms are reacting to the compliance needs expressed by their customers. The customers react directly to the environmental regulation, and they pass on their equipment and system needs to the environmental technology firm. The path from environmental regulation through the regulated firm to the environmental technology firm, in the environmental-innovation model, describes this channeling of the regulatory response through the customer. The separation of the regulatory response into (a) and (b) thus allows the relative strengths of the paths through the environmental-innovation model to be observed. Although it is possible that the customer firm may also adopt environmental technology in response to influences that have no regulatory form, for example public pressure, or a proactive corporate environmental ethic, I test for this possibility and find that environmental regulations are the prime motivation for technology adoption.

Each Water and Wastewater Technology firm in the mail-out survey was asked to report on up to three of their most important technologies. Question 5 of the survey questionnaire (see Appendix 3), in particular, asked the respondent firms to rank in order of importance the three motivations for the development of their technologies. Although a fourth category ('other') was also available for firms to rank, no firm indicated an alternative to the three influences already listed. The purpose of asking the firms to rank the influences on their innovation process was, first, to evaluate the role of environmental regulation as a key influence on the development of water and wastewater technology, and second, to observe the relative strengths of the different paths through the environmental-innovation model. There were no tied ranks for question 5.

The survey method of gathering data on each of the individual technologies introduced by firms is referred to as the 'object approach' in the 'Oslo Manual' of the OECD (OECD 1997). This approach is particularly useful in research projects that analyze the effect of government policies in promoting particular types of innovation, as is the case here. A summary of the results from the mail-out survey is provided in Table 5.1. The rows of the table refer to up to three of the stimuli or influences on the firm's innovation process. The columns indicate the strength of each influence on the technologies produced by the WWT firms.[2] The responses assigned to each cell are the individual technologies reported by the WWT firms, giving 78 technologies in all, as indicated by the row totals. The percentages are

[2] The first column of Table 5.1 is drawn from the categories of stimulus given in survey question 5 (Appendix 5). However, I have used their meanings in the table and subsequent text rather than the actual category names. This interpretation of the categories of stimulus was confirmed with

given in the parentheses. The column 'no rank indicated' refers to technology cases where no rank was assigned to a particular stimulus.[3]

questionnaire pre-testing

[3] In the following analysis and tables, the ranks are interpreted as responses assigned to each innovation stimulus. The most important influence (receiving a rank of 1) is referred to as 'strong'. The remaining ranks were deemed to be moderate (rank 2) or weak (rank 3), reflecting the importance of each.

Table 5.1: Frequency Distribution of Water and Wastewater Technologies by Rank of Innovation Stimulus
(percentages)

	Rank				
Stimulus	**First**	**Second**	**Third**	**No Rank Indicated**	**Total (Technologies)**
Direct Response to Environmental Regulation	21 (27)	19 (24)	16 (21)	22 (28)	78 (100)
Response to Customer Needs	52 (67)	8 (10)	7 (9)	11 (14)	78 (100)
Speculated Future Demand	5 (6)	17 (22)	22 (28)	34 (44)	78 (100)

Source: Survey Data

5.1.1 Direct Response to Environmental Regulation

This stimulus captures the fact that environmental technology firms are aware of the current environmental regulations and they have developed technologies in anticipation of demand from the firms subject to the regulation. The interaction of environmental policy and innovation research suggests that an important secondary policy impact of environmental regulation (after ecosystem protection), is the development of environmental technology. The stronger its role as a technological stimulus, the more this indicates that it plays a direct role on the actions of the technology manufacturers. This is consistent with Ashford's model, presented in Chapter 3.

From the data presented in Table 5.1, it is evident that environmental regulation is a pervasive influence on the development of water and wastewater technology in Ontario. However, for only 27% of technologies reported was environmental regulation deemed to be a strong stimulus, and therefore, a singular influence on the technological strategies of the water and wastewater technology firms[4]. Interviews revealed that typically, the firms that made these responses are fully aware of the technical requirements of the environmental regulation, and produce compliance technology in anticipation of demand from firms who are subject to the environmental regulation. As far as we know from the survey, the remaining 45% of technologies were developed with environmental regulation acting only as a moderate or weak direct influence on the decision to develop a particular technology. This result alone in Ontario indicates that WWT firms do not react directly and strongly to environmental regulations contrary to the central thesis of the environmental policy and

[4] 19 firms responded in this way.

innovation literature.

Looking at the role played by *specific* policy instruments, Ontario's environmental regulations figure more prominently than Federal and US Environmental Protection Agency regulations (Table 5.2).

Table 5.2: Influence of Environmental Regulation on Technology Development, by Regulation Type

JURISDICTION	TYPE OF REGULATION	NUMBER OF CASES (N=56)	PERCENTAGE
	Don't Know	8	14 %
Ontario	MISA OWRA	18 20	32 % 36 %
Federal (Canada)	Fisheries Act	4	7.2 %
US	EPA	6	11 %

Source: Survey Data

In 14% of cases where environmental regulations were reported as influencing technology development, the firm's reported that they didn't know what the regulatory influence was. Initially, this seemed strange, however, in the subsequent follow up interviews with a number of these firms, it was revealed that they were in fact, reacting to the requirements of their customers and environmental regulation was an indirect influence on their innovation decisions. While they were aware of the technical requirements for compliance by their customer (for example minimum allowable concentrations of specified toxic substances in a wastestream), they were not familiar with the particular regulation mandating these concentrations. They didn't know, for example, if it was the OWRA as opposed to MISA, or even the Fisheries Act. Consequently, they indicated on the questionnaire that they 'didn't know' which regulations they were influenced by. Of the remaining technologies, 68% were developed under the influence of Ontario's regulations, namely the MISA program (32%), and the Ontario Water Resources Act (36%). Approximately 7% were influenced by the Federal Fisheries Act (notably the Pulp and Paper Effluent Regulations), while the remaining 11% were developed under the influence of regulations set by the United States Environmental Protection Agency (USEPA). The importance of local policy circumstances (expressed in the MISA program and the OWRA), as influences on the process of technology development in the environmental technology industry is consistent with Porter (1990), who argues that domestic or local environmental policies can be an important driver of a successful, domestic environmental technology industry.

5.1.2 Responding to Customer Needs

Users of environmental technology exercise an important demand for equipment with particular performance characteristics. As discussed in Chapters 2 and 3, environmental regulation creates a need for environmental technology from firms that are subject to its requirements. The regulated firms will then decide how best to meet those requirements. This may mean developing technology themselves, buying technology 'off-the-shelf' from an environmental technology firm, or engaging in some form of interactive activity with the environmental technology firm to co-develop a technological solution. The role that customers play in the technological activity of the environmental technology firm, therefore, will be varied. When the environmental technology firm supplies technology in an off-the-shelf fashion, only a minor degree of interaction and equipment customization is involved. In this case, the customer has little opportunity or desire to be involved in the decision to develop the technology. As the level of interaction between the environmental technology firm and the regulated firm increases then the role of the regulated customer as a stimulus for the development of the technology will increase, too. This will indicate a much stronger, interactive role between the two actors in the innovation process.

The technological output of the WWT firms has been developed predominantly in response to the current needs of individual customers (Table 5.1). In contrast to the direct role played by environmental regulation as an innovation stimulus, the customer exerts a much stronger influence on the technology development activity of the WWT firms. In 67% of cases, the needs of individual customers were deemed to be a strong stimulus for the development of the technology, compared with only 27% in the case of environmental regulation. This result indicates that the user of the technology, the regulated firm, directly influences the development of environmental technology by WWT firms, and consequently, is a necessary agent in the innovation process. In addition, when the WWT firms were asked to evaluate how important their relationship with their customers was to their technological strategy overall, 68% indicated the customer's role was very important, 26% indicated the customer played a moderate role, and 6% said the customer played no role in their innovation process (Table 5.3).

Table 5.3: Importance of Customer Relationship to WWT firm's Technological Strategy

	NUMBER OF FIRMS (N=35)	PERCENTAGE
Not Important	2	6
Moderately Important	9	26
Very Important	24	68

Source: Survey Data

The strong linkage that exists between the environmental technology firms and their customers is evidence of the existence of an interactive innovation process. The nature of these linkages will be explored in the following chapter.

5.1.3 Expectation of a Future Market

The speculation by environmental technology firms of future demand for compliance technology also stimulates the innovation process. This captures the influence of growing public pressure for the preservation of environmental integrity, or the existence of international environmental agreements and desirable standards that are not formally expressed as regulations. Examples of factors in this category include the set of ISO 14000 environmental management standards from the International Organization for Standardization, or various international agreements on atmospheric and water quality[5]. In other words, this stimulus for innovation comes from the WWT firm's own perception of the

[5]Examples include the Great Lakes Water Quality Agreement, the Montreal Protocol and the atmospheric air quality agreements of the UN Rio and Kyoto conferences.

existence of a future market for their technology. Although customers may eventually become involved in the process of technology development, this will be *ex post* adaptation, as the technology will be supplied in an 'off-the-shelf 'fashion. This is consistent with Kline and Rosenberg (1986) who argue that an important element of their chain-linked model of innovation is that new technological designs can create new market possibilities (see Chapter 3).

This speculation of a future market captures one dimension of the innovation process that occurs even when environmental regulation is absent, unenforced, or is set at too low a level of performance. In Chapter 3, it was argued that environmental regulation was required as a fundamental part of the innovation process, without it the process would be weak. For that reason, it was not anticipated that expectations of a future market would be a strong stimulus for technology development. This is confirmed by the survey results (Table 5.1), as the speculation of future demand plays a weak or moderate influence as an innovation stimulus. In only 6% of the technologies reported in this survey, was it a strong or direct stimulus. In all of these cases, the direct response of environmental regulation was reported as the next ranking influence. In similar fashion, the speculation of future demand was the next ranking stimulus to the current needs of customers. This indicates that even in cases where environmental technology firms act in a more speculative or anticipatory fashion regarding technology development, this occurs within the influence of environmental regulation. Porter (1990) argues that environmental technology firms can gain a competitive advantage when they speculate about increases in the stringency of environmental regulation. His key assumption for this view is that the environmental regulations are reviewed regularly and are ratcheted upwards, and offensive firms will perceive the pattern and respond.

However, the environmental regulations in Canada, both at the provincial and federal levels, are not reviewed regularly and consequently are not advanced in a predictable pattern. Review tends to take place only as a reactive measure after some event for example, a major discharge of toxic substances into a watercourse. The MISA program was established in this way. Because changes in regulations in Ontario are not predictable and not generally anticipated, environmental technology firms tend to advance technology to meet the user needs at any one time. The effect of regulatory stability is to reduce the incentive to create new technology, and as a result few firms act in a speculative way or an anticipatory fashion, and Porter's argument does not apply in this region. At best, the speculation of future demand is secondary to the direct or indirect regulatory response: in only 5 cases was the speculation of future deemed to be the strongest influence on technology development.[6]

Taken together, these results suggest that the model of the environmental-innovation process, as specified in Chapter 3, is a fair representation of what can be observed. There is a linkage from environmental regulation to both the environmental technology firm and the regulated firm, although this linkage is stronger for the regulated firm. A strong linkage also exists from the regulated firm to the environmental technology firm, and the initial indicators are that this is a two-way path, indicating an interactive relationship. This will be explored in greater detail in the following chapter.

5.2 Innovation Stimuli by Technology Type

The results reported above indicate that environmental regulation, as a stimulus for innovation, is channeled more strongly through the compliance needs of customers, than

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[6] The firms producing these technologies are small "Multi-technology' firms, focused on the

directly to environmental technology firms. Nevertheless, there are two general types of technology, and these results need to be probed further to discover if there are significant differences. This section addresses the relationship between the three innovation stimuli and the type of technology developed by the WWT firms.

In each of the three chi-square tests reported below, the columns indicate the strength of each innovation stimulus, drawn from the data presented in Table 5.1. However, the second and third ranks have been combined in order to allow the test to be performed without violating the cell expected frequency rule, and the terms 'strong' and 'weaker' influences have been used in the discussion. The column entitled 'no rank indicated' represents cases where no rank was indicated for the innovation stimulus.

5.2.1 Direct Response to Environmental Regulation and Technology Type

According to the environmental policy literature, the *type* of environmental regulation employed by the regulatory agency will influence the type of environmental technology that is developed by environmental technology firms. The use of technology-based standards will result in the development of end-of-pipe technologies, while the application of performance based standards will result in the development of process-integrated technology (Magat 1979, Laplante 1990, Ashford 1993,1994). Indeed, Ashford is quite explicit about this relationship as he declares that the technological output of the environmental technology firms will be end-of-pipe technology, developed in response to technology-based standards (see Figure 3.3, Chapter 3). Because the dominant environmental policy instrument in Ontario is the

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production of 'new' technology, see section 6.3, Chapter 6.

application of certificates of approval and control orders under the Ontario Water Resources Act, and these usually require the adoption of specific technologies, the expectation is that more end-of-pipe technology would be reported in the survey.

Table 5.4: The Relationship between Technology Type and the Influence of a Direct Response to Environmental Regulation

Count (Row Pct) (Col. Pct)	**No Rank Indicated**	**Weaker Influence**	**Strong Influence**	Row Total
End-of-Pipe	**17** (37.8) (77.3)	**17** (37.8) (48.6)	**11** (24.4) (52.4)	**45** (57.7)
Process-integrated	**5** (15.2) (22.7)	**18** (54.5) (51.4)	**10** (30.3) (47.6)	**33** (42.3)
Column Total	**22** (28.2)	**35** (44.9)	**21** (26.9)	**78** (100)

Chi-Sq. .= 4.891	DF = 2	p = .0866

As reported in Table 5.4, there are indeed more cases of end-of-pipe technologies developed by the WWT firms, than process-integrated technologies. Approximately 58% of all technologies produced by WWT firms were end-of-pipe compared with approximately 42% that were process-integrated technology. While this would seem to support the hypothesis that the dominant use of technology-based standards will result in more end-of-pipe technology, the direct influence of environmental regulation on the development of the different types of technology is insignificant (p = .0866). When regulation does influence technology development, whether it is a strong or weaker influence, it is no more likely to produce end-of-pipe technology than process-integrated technology.[7]

5.2.2 The Direct Response to Customer Needs and Technology Type

Similarly, there is no statistically significant influence of a direct response to customer need on the type of technology developed (Table 5.5). A strong association was expected between the needs of individual customers and the more complex process-integrated technologies. These results suggest however, that neither process-integrated nor end-of-pipe is favoured by the customer of the technology. Consequently, the contention held in the innovation literature that strong customer-user relationships are more likely to exist in cases where technologies are cutting edge, or non-standardized state-of the-art doesn't necessarily hold. End-of-pipe technologies (which are a 'standardized' technological approach to achieving environmental compliance), exhibit the same degree of customer-supplier interaction as that of process-integrated technologies. The reasons for this pattern will be explored in the following chapter.

[7] Chi-sq. test is insignificant at p=0.05, between technology type and regulation type, Table 5a, Appendix 5.

Table 5.5: The Relationship between Technology Type and the Influence of a Response to Customer Needs

Count (Row Pct) (Col. Pct)	**No Rank Indicated**	**Weaker Influence**	**Strong Influence**	Row Total
End-of-Pipe	**7** (15.6) (63.6)	**8** (17.8) (53.3)	**30** (66.7) (57.7)	**45** (57.7)
Process-integrated	**4** (12.1) (36.4)	**7** (21.2) (46.7)	**22** (66.7) (42.3)	**33** (42.3)
Column Total	**11** (14.1)	**15** (19.2)	**52** (66.7)	**78** (100)

Chi-Sq. = .276	DF = 2	p = .841

5.2.3 The Speculation of Future Demand and Technology Type

In contrast to the two innovation stimuli discussed above there appears to be a statistically significant association between future demand and process-integrated technology (Table 5.6). However, two of the six cells in Table 5.6 yielded expected frequencies of less than 5, thus violating the expected frequency rule of the test. When the cells 'strong' and 'weaker' are collapsed to form a 2 x 2 table, no rules are violated but a weaker test result is obtained (Chi-Sq. = 3.22; p = .042). The reason is the pooling of contrary technology trends in response to future demand. For both end-of-pipe and process-integrated technologies, the speculation of future demand was a weaker influence behind either a direct response to environmental regulation or a direct response to customer needs. This is likely to be a reaction to environmental regulation.

Table 5.6: The Relationship between Technology Type and the Influence of the Speculation of Future Demand

Count (Row Pct) (Col. Pct)	**No Rank Indicated**	**Weaker Influence**	**Strong Influence**	Row Total
End-of-Pipe	**24** (53.3) (70.6)	17 (37.8) (43.6)	**4** (8.9) (80.0)	**45** (57.7)
Process-integrated	**10** (30.3) (29.4)	**22** (66.7) (56.4)	**1** (3.0) (20.0)	**33** (42.3)
Column Total	**34** (43.6)	**39** (50.0)	**5** (6.4)	**78** (100)

Chi-Sq. = 6.513	DF = 2	p = .038

In addition to the different types of technology, the environmental-innovation model must be able to account for size and ownership differences among the environmental technology firms. As indicated in Chapter 3, the model recognizes that in addition to different policy regimes and different technology types, the characteristics of the environmental technology firms are important for a thorough understanding of the relationship between environmental regulation and innovation. Therefore, the following two sections address the operation of the model with respect to ownership and size differences between the WWT firms.

5.3 Firm Ownership

The survey data reveal that environmental regulation, as an innovation stimulus is channeled more directly towards Canadian owned firms as opposed to foreign-owned firms (Table 5.7). For approximately 80% (combining the weaker and strong categories) of the technologies developed by Canadian owned firms, environmental regulation was deemed to have played a role in stimulating their development. In the case of foreign technology, approximately 47% were developed under the influence of environmental regulation. As a result, there is a statistically significant difference between the strength of environmental regulation as a stimulus for technology development, and the ownership of the firm producing the technology (p=.0059).

Table 5.7 The Relationship between Firm Ownership and the Influence of a Direct Response to Environmental Regulation

Count (Row Pct) (Col. Pct)	**Canadian**	**Foreign**	Row Total
No Rank Indicated	**12** (54.5) (20.3)	**10** (45.5) (52.6)	**22** (28.2)
Weaker Influence	**32** (91.4) (54.2)	**3** (8.6) (15.8)	**35** (44.9)
Strong Influence	**15** (71.4) (25.4)	**6** (28.6) (31.6)	**21** (26.9)
Column Total	**59** (75.6)	**19** (24.4)	**78** (100)

Chi-Sq. .= 10.25	DF = 2	p = .0059

Foreign-owned firms indicated that environmental regulation influenced the development of only 47% of their technologies. What is interesting about this result is that Ontario's environmental regulations, in contrast to regulations promulgated under the USEPA, were the principal regulatory influence on their technological output. Foreign-owned firms were expected to transfer technologies that had been developed in their home location in response to their domestic regulations, as many of the Ontario statutes have been written with reference to the regulatory approach used in the US.[8]

The foreign-owned firms have already produced technology that allows compliance with the US statutes, but because these statutes have been modified to fit Ontario's water pollution problems, their technologies have to be modified accordingly. The modification will typically involve adjustments to allow the removal of particular toxic substances not listed in the US statutes, or an adjustment to suit the changes in the maximum allowable concentrations of other pollutants. Overall, 75% of the foreign-owned firms indicated that they had adjusted their technology to suit the requirements of the regulations in Ontario. It should be noted at the same time, that the majority of Canadian firms who export technology also indicated that they have modified their technology to suit the environmental regulations in their export markets (Table 5b, Appendix 5). In all of these cases, the modifications were, at best, deemed a moderate adjustment rather than a complete re-design of their technology.

It would be plausible for foreign-owned firms to merely transfer technology to their customers in an off-the-shelf fashion. As a result, the customer was expected to play little

[8] For example, in the case of the MISA program, the 'Best Available Technology' criterion has been adopted from the same criterion used in the US Clean Water Act (Salamon et al 1990, Koch and Leone 1979). In an interview with the Science and Technology Branch of the Ontario Ministry of the Environment, the respondent stated that although the MISA program was a new approach to controlling industrial pollution in Ontario, it was in fact:, "*nothing more than a glorified USEPA*

role in the innovation process. At best, they might become involved in some very minor modifications of the technology, but the principal method of technology transfer would be through arm's length relationships with their customers. However as Table 5.8 indicates, the need to respond directly to individual customers is just as important to foreign-owned firms as it is to Canadian owned firms. Therefore, the role of the customer as a stimulus for innovation is strong for all firms regardless of their ownership structure. Of the 19 technologies produced by foreign-owned firms, 13 (68.4%) were developed with the customer playing a strong role in the innovation process. This result is interesting given the typically held belief in the innovation literature that foreign-owned firms will supply technology in an off-the-shelf fashion in the host country.

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approach tailor made to Ontario".

Table 5.8: The Relationship between Firm Ownership and the Influence of a Direct Response to Customer Need[9].

Count (Row pct) (Col. Pct)	**Canadian**	**Foreign**	Row Total
No Rank Indicated	**7** (63.6) (11.9)	**4** (36.4) (21.1)	**11** (14.1)
Weaker Influence	**13** (86.7) (22.0)	**2** (13.3) (10.5)	**15** (19.2)
Strong Influence	**39** (75.0) (66.1)	**13** (25.0) (68.4)	**52** (66.7)
Column Total	**59** (75.6)	**19** (24.4)	**78** (100)

Chi-Sq. .= 1.861	DF = 2	p = .394

Foreign-owned firms are expected to specialize in the production of end-of-pipe technology as opposed to process-integrated technology (Hypothesis 4). This expectation is driven largely by the fact that foreign-owned firms will, typically, transfer technology to the host economy, that has been developed in the home economy (Britton and Gilmour 1978, Hayter 1982, 1997). Because the majority of the foreign-owned firms in this enquiry are US owned, and given the given the dominance of technology-based approaches to regulation there, they would be expected to transfer the more standardized end-of-pipe technology they

[9] For this Chi-Square test, 33% of the cells had expected frequencies of less than 5. Collapsing the columns weaker and strong to remove the cell frequency violation, does not change the significance of the test. Therefore the result of the test holds. The revised test is shown in Table 5c, Appendix 5.

have generated for the US market in response to US regulations. The Canadian owned firms would also be expected to generate more end-of-pipe technology given the dominance of technology-based approaches to regulation operating in Ontario.

Table 5.9: The Relationship between Firm Ownership and Technology Type

Count (Row Pct) (Col. Pct)	**Canadian**	**Foreign**	Row Total
End-of-Pipe	**34** (70.8) (57.6)	**14** (29.2) (63.6)	**48** (59.3)
Process-integrated	**25** (75.8) (42.4)	**8** (24.2) (36.4)	**33** (40.7)
Column Total	**59** (72.8)	**22** (27.2)	**81** (100)

Chi-Sq. .= .239	DF = 1	p = .624

This expectation of the technology supplied by both foreign-owned and Canadian owned firms is supported by the data (Table 5.9). Approximately 64% of the technologies produced by foreign-owned firms can be classified as end-of-pipe, but this is similar to the Canadian owned firms with approximately 58% of their technological output being end-of-pipe. Therefore, the type of technology produced does not vary according to the ownership of the firm producing it.

5.4 Firm Size

In addition to firms of different ownership types, the environmental-innovation model must be able to function with firms of different sizes, for it to be considered a true representation of the process underpinning the development of environmental technology. This is particularly important in the case of Ontario, given that the most frequent size category in the WWT sector is small firms of less than 50 employees (Table 4.4, Chapter 4). As the innovation literature suggests, firms of different sizes have different abilities with respect to technology development, consequently, the model must be inclusive.

Taking Tables 5.10 and 5.11 together, the roles played by both a direct response to environmental regulation, and the response to current customer needs as stimuli for innovation, do not vary significantly with the size of the WWT firm. In reacting to the current needs of individual customers (Table 5.11), it appears that small firms are not at a significant disadvantage, due to their size. Although the character of these links is explored further in Chapter 6, this first indication suggests that small firms have been able to overcome their size disadvantage by establishing interactive links with customer firms.

Table 5.10: The Relationship between Firm Size and the Influence of a Direct Response to Environmental Regulation

Count (Row pct) (Col. Pct)	**Small**	**Large**	Row Total
No Rank Indicated	**9** (40.9) (21.4)	**13** (59.1) (36.1)	**22** (28.2)
Weaker Influence	**24** (68.6) (57.1)	**11** (31.4) (30.6)	**35** (44.9)
Strong Influence	**9** (42.9) (21.4)	**12** (57.1) (33.3)	**21** (26.9)
Column Total	**42** (53.8)	**36** (46.2)	**78** (100)

Chi-Sq. = 5.55	DF = 2	p = .062

Table 5.11: The Relationship between Firm Size and the Influence of a Direct Response to 'Customer Need'

Count (Row pct) (Col. Pct)	**Small**	**Large**	Row Total
No Rank Indicated	**3** (27.3) (7.1)	**8** (72.7) (22.2)	**11** (14.1)
Weaker Influence	**11** (73.3) (26.2)	**4** (26.7) (11.1)	**15** (19.2)
Strong Influence	**28** (53.8) (66.7)	**24** (46.2) (66.7)	**52** (66.7)
Column Total	**42** (53.8)	**36** (46.2)	**78** (100)

Chi-Sq. .= 5.418	DF = 2	p = .062

Firm size does not determine the type of technology manufactured. Small firms, because they typically face higher transaction costs with respect to technology development, might be expected to produce the more standardized end-of-pipe technology. Conversely, the large firms would be expected to produce mainly process-integrated technology, as they are better able to absorb the costs of performing research. The data, however, do not support these expectations (Table 5.12). Although small firms produce more end-of-pipe technology, there is almost an even distribution of both technology types among the large firms. Consequently, the statistically insignificant relationship (p=.074) between the type of technology developed and the size of the firm indicates that the complexity of technology produced will not vary according to the size of the firm.

Table 5.12: The Relationship between Firm Size and Technology Type

Count (Row Pct) (Col. Pct)	**Small**	**Large**	Row Total
End-of-Pipe	**29** (60.4) (69.0)	**19** (39.6) (48.7)	**48** (59.3)
Process-integrated	**13** (39.4) (31.0)	**20** (60.6) (51.3)	**33** (40.7)
Column Total	**42** (51.9)	**39** (48.1)	**81** (100)

Chi-Sq. = 3.462	DF = 1	p = .074

5.5 Discussion of the Factors Influencing the Environmental-Innovation Process

The purpose of this chapter was to establish the presence of an innovation process underlying the development of water and wastewater technology. In doing so, it would confirm the assumptions about the process of environmental technology development as described in the environmental-innovation model in Chapter 3.

In particular, this first set of analyses has established the presence of an innovation process, of the type described by the environmental-innovation model. Working through the model, environmental regulation does indeed influence the development of water and wastewater technology. However, the path through which this influence is channeled does not conform to the originally held expectation. Drawing on the work of Ashford (1993, 1994), environmental regulation was assumed under Hypothesis 1 to act as a strong and therefore a direct motivation for the development of environmental technology. This would be consistent with the direct link from environmental regulation to the environmental technology firm, in the environmental-innovation model. However, the evidence drawn from the Water and Wastewater Technology sector in Ontario indicates that this direct link is not as strong as originally expected. Instead, the regulatory influence is channeled through the compliance needs of the regulated firms. The environmental technology customers, although acting in compliance with environmental regulation, play a much stronger role in directing the innovation process. As indicated by Tables 5.5, 5.8 and 5.11, the role of the customer as an important stimulus for innovation does not vary according to the type of technology developed, the ownership of the firm nor the size of the firm. Therefore, its role as an innovation stimulus is consistent among all firm types.

While the strength of a direct response to environmental regulation as an innovation stimulus does not vary according to the size of the WWT firm (Table 5.10), nor the type of technology the WWT firms are developing (Table 5.4), it does vary according to the ownership of the WWT firm (Table 5.7). Although Canadian owned firms indicated that domestic environmental regulations influenced their innovation process, foreign-owned firms also indicated that Ontario's regulations as opposed to regulations in their home locations, were important. Hypothesis 3 assumed that the foreign-owned firms would react to the environmental regulations in their home location that would allow them to gain a competitive advantage in the supply of environmental technology in Ontario. Porter (1990) who suggests that local policy circumstances will confer a competitive advantage on domestic suppliers of environmental technology drove this assumption. His argument is based upon the fact that as other jurisdictions 'race to catch up' with stringent local regulations, the domestic environmental technology firms will benefit from an early mover advantage in their export markets. This advantage is drawn from the fact that they already have experience innovating to meet their own domestic local policy requirements. The assumption is that those other jurisdictions will implement regulations that are, at least, similar to those already in use. This is largely true in the case of Ontario, given the fact that the regulations have been written using the US regulations as a template. However, the fact that they have been 'tailored' to suit local environmental conditions requires the foreign-owned firms to meet those local conditions even though they have existing experience meeting similar regulations in the US. This tempers the early mover advantage somewhat, and allows local, Canadian owned firms to compete.

Hypothesis 2 held that the type of environmental regulation employed by the regulatory agency directly influenced the type of environmental technology developed by the firms. This assumption was driven in large part by Magat (1979), Laplante (1990) and Ashford (1993, 1994) among others, who argue that the use of performance standards will result in the development of process-integrated technology, while technology-based standards will result in the development of end-of-pipe technology. Although, as reported in Table 5.4, more end-of-pipe technology is produced overall, this category of environmental technology is no more likely to be produced under the influence of environmental regulation than process-integrated technology, as indicated by the statistically insignificant relationship between the two variables. Therefore, environmental regulation does not act directly as a means to select between alternative paths of technological development. Given the dominance of the technology-based 'approvals process' in Ontario, it suggests that the assumption held by the environmental policy literature needs modification. This result can be explained with reference to the fact that the response to environmental regulation is channeled through the technological requirements of the regulated firms.

Environmental regulations will compel the regulated firms to seek a technological solution in order to achieve compliance. Under a performance standard, such as exists under MISA or the Fisheries Act, the regulated firm will decide upon a technological solution in accordance with their particular production process. In some cases this might involve the use of an end-of-pipe technology, in others a process-integrated technology. In all of these cases, they will cooperate technologically with the environmental technology firm. Likewise, under a technology-based standard as exists with the 'approvals process' of the OWRA, the regulated firm will apply for a license stating the technological approach to be used to achieve environmental compliance. The choice of technology will be made in cooperation with the environmental technology firm. Interviews with the representatives of Ministry of the Environment revealed that the certificate of approval will usually be granted for the technology stated in the original application. It is only when firms fail to achieve compliance under their existing certificate, and the ministry issues a control order, that *specific* technologies will be mandated. Typically, these will be end-of-pipe technologies. In both scenarios, the regulated firm reacts directly to the regulations, and in cooperation with the environmental technology firm, decides on a technological solution. Although the level of cooperation varies in intensity from an arm's length relationship with minor modifications up to the co-development of completely new technology, the choice of technology is directed more by the customer-supplier relationship, than by environmental regulation. In addition, as reported in Table 5.5, there is no significant relationship between the type of technology developed and the reaction of WWT firms to individual customer needs. Consequently, Ashford (1994) is mis-specifying the relationship between the type of technology used for compliance and the regulatory approach by government. Under Ashford's scenario, and as indicated in Chapter 3, the environmental technology firm will only produce end-of-pipe technology. As demonstrated here, environmental technology firms will produce a variety of technologies in accordance with the requirements of the regulated firms rather than as a direct response to the technical requirements of environmental regulation.

The speculation of future demand for technology's role as an innovation stimulus is secondary to environmental regulation, regardless of how the regulatory influence is channeled. The low number of technologies developed under the strong influence of speculated future demand indicates that the environmental-innovation model would describe a weak process if it were not for the stimulus of environmental regulation acting upon the environmental technology firm and the regulated firm. Consequently, issues such as pressure from a more environmentally conscious public, or voluntary environmental standards will not act as a direct stimulus for innovation by environmental technology firms. In fact, interviews with both the WWT manufacturers and the regulated firms indicate that voluntary agreements are not an important influence on the innovation process. However, the technology manufacturer rather than the regulated firm voiced this view more strongly. All 5 of the environmental technology users who were interviewed have heard of ISO 14000, but in only two cases were the firms registered as an ISO 14000 firm. The remaining 3 firms had no immediate plans to become compliant deeming it to be either unimportant for their current business strategy, or too expensive to become registered. In one of the registered firms, a producer of chemicals, the Canadian Chemical Producer's Association's Responsible Care Programme was considered to be of greater importance. However, the firm admitted they used this more as a public relations strategy than a statement of their environmental awareness. They also admitted to debating whether to include membership in the Responsible Care Programme or their ISO 14000 compliance on their business cards in addition to their ISO 9000 status. In the end they opted for the Responsible Care Programme as they deemed this to be more instantly recognizable by their suppliers and customers. The firm added however, as did all the regulated firms interviewed, that environmental regulations were of stronger influence on their manufacturing activity than voluntary corporate strategies. Consequently, the existence of voluntary programmes in no way replaces the requirement for the firm's need to comply with environmental regulations.

The combination of the relationships discussed in this chapter illustrates the existence of an innovation process of the type advanced in the environmental-innovation model in Chapter 3. Although environmental regulations will influence the development of environmental technology, the path through which this influence travels is via the regulated firm rather than directly to the environmental technology firm. Once the regulated firms are forced to comply with environmental regulation, they will interact with the environmental technology firms in order to achieve a technological solution. The form of interaction, which is examined explicitly in the following chapter, will not vary according to the type of technology developed, the ownership of the firm, nor the size of the firm. As a result, the innovation process, as indicated by the environmental-innovation model exists with the linkages as specified, and does not require re-specification for different ownership or size structures, nor different technology types.

5.6 Chapter Summary

Using the Water and Wastewater technology sector as an example, this chapter has established the existence of an innovation process governing the development of environmental technology. The results of the analytical tests indicate that the characteristics of this innovation process are of the form specified in the environmental-innovation model in Chapter 3.

The analysis indicates that environmental regulation is indeed, an important component of the environmental-innovation process. However, the initial expectation that it would be a strong direct influence on the actions of the environmental technology firms has been proven to be incorrect. Instead, the influence of environmental regulation on the development of environmental technology is channeled through the compliance needs of individual customers. Consequently, the linkages between the producers of environmental technology and their customers are a critical part of the environmental-innovation model. The characteristics of these customer-supplier linkages are examined in the following chapter.

Chapter 6: Exploring the Structure of the Innovation Process among Water and Wastewater Technology Firms.

6.0 Introduction

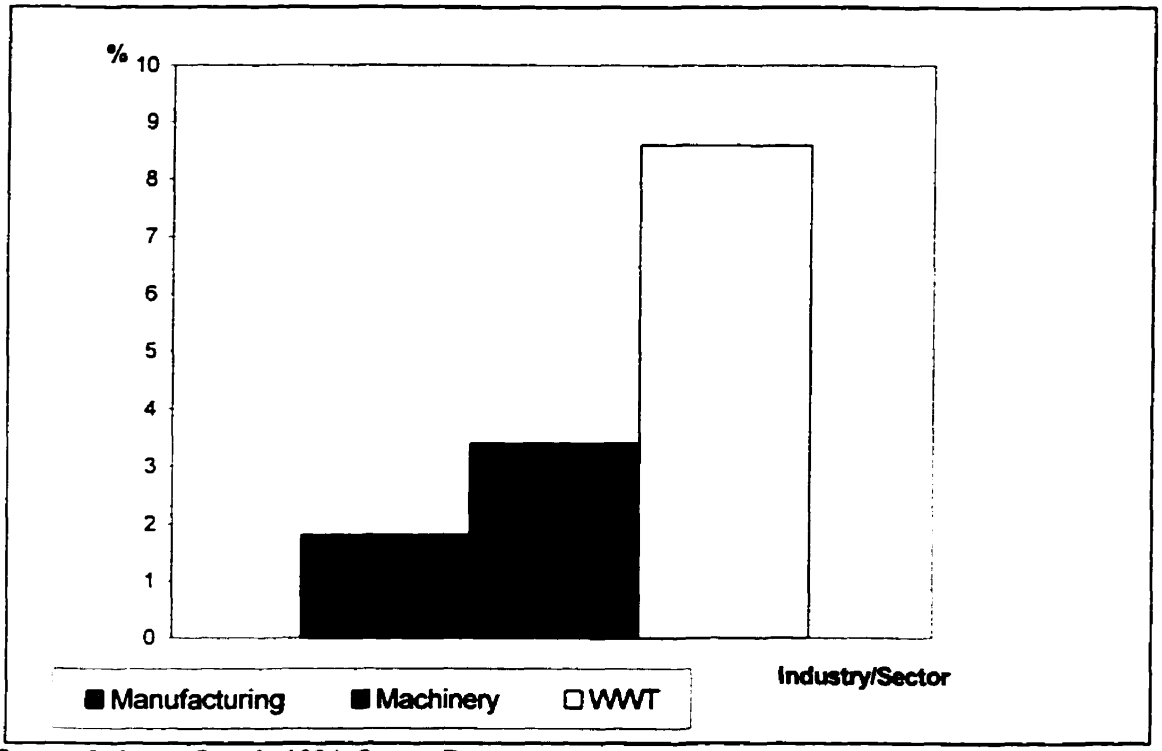
The purpose of this chapter is to verify the characteristics of the linkages between the suppliers and users of the environmental technology. We have already observed the general form of the innovation process that governs the development of water and wastewater technology in Ontario. The particular form of the innovation process however, hinges on the nature of the relationship between the WWT firms and their customers. This relationship is fundamental to the operation of the environmental-innovation model. At the outset then, this chapter is concerned with evaluating Ashford's arms-length model of technology generation, and challenges its applicability in Ontario.

It is logical that we begin with an examination of how innovative the WWT firms are. To do this, reference is made to the R&D intensity of the firms. Then the relationship between the WWT firms and their customers is described explicitly. In the concluding part of the chapter, I establish the considerable degree of variability of the firms that develop water and wastewater technology.

6.1 Innovation Intensity of the WWT firms

In order to assess how innovative the Ontario WWT firms are, the survey questionnaire (Question 15, 1995 value) requested information on the proportion of revenue they spent on research and development. This commonly used approach, which is referred to as R&D intensity, measures the proportion of the firm's gross annual sales that is devoted to R&D.[1] The average R&D intensity for all WWT firms is 8.6% (Figure 6.1).[2] This compares favorably with the R&D intensity ratio of 1.8% for manufacturing as a whole, and 3.4% for Machinery in particular, the closest Industry Canada defined SIC sector to the WWT sub-sector.

Figure 6.1: R&D Intensity by Industry/Sector



Source: Industry Canada 1994, Survey Data.

Compared with the OECD standard of 3%, virtually all firms are meeting a high

[1] See Arundel, A, van de Paal, G, and Soete, L (1995), and Industry Canada (1994).
[2] While the 'Manufacturing' and 'Machinery' categories refer to Canada as a whole, the 'WWT' category refers to the Ontario industry. Because 60% of the national WWT industry is located in Ontario, it can be used as a proxy for the national extent of the industry.

standard of R&D intensity – only 5 of 35 firms are low spenders (Table 6.1).[3] Nevertheless, a more thorough understanding of the nature of the innovativeness of the Ontario industry can be achieved by disaggregating the data according to the structure of the industry sub-sector. In particular, and for the purposes of further analyzing the environmental-innovation model, we can explore the level of R&D intensity by firm size and firm ownership, and the type of technology the firms are manufacturing.

Table 6.1: Distribution of WWT firms by R&D Intensity (OECD Classification)

R&D Intensity Level	Number of Firms	Percentage
< 1%	3	8.3
1.0% – 2.9%	2	5.6
>3%	31	86.1
TOTAL	35	100.0

Source: Survey Data

Using R&D intensity, the firms have been ordered into four groups –low, medium-low, medium-high, and high, recognizing clustering and natural breaks in the data. The distribution of WWT firms according to this revised classification is shown in Table 6.2. The largest group is anchored around the OECD standard, but higher R&D intensities identify three other clusters of firms.

[3] See Arundel, A et al (1995)

Table 6.2: Distribution of WWT Firms by R&D Intensity (Revised Classification)

R&D Intensity Level	**Number of Firms**	**Percentage**	**Mean R&D %**
Low (1% – 5 %)	13	36.1	3.46
Medium-Low (6% – 9%)	11	30.6	7.1
Medium-High (10% - 14%)	8	22.2	10.1
High (>15%)	4	11.1	18.7
TOTAL	36	100.0	

6.1.1 Firm Size and Innovativeness

There is considerable interest in the innovation literature about small and large firm differences in technology development (for example Rothwell and Zegveld 1982, Baldwin 1996, Freeman and Soete 1997). Consequently, the relationship between innovativeness and the size of the WWT firm was tested. The results coincided with those reported in Chapter 5 (Table 5.12) which indicated that the type of technology manufactured did not vary significantly according to the size of the firm manufacturing it. There was evidence of a specialization towards the more standardized end-of-pipe technologies by small firms, however, statistically this level of specialization was not significant. Although small firms produce more end-of-pipe technology, they are not less innovative than large firms (Table 6.3). Of the 12 firms who indicated a medium-high or a high level of R&D intensity, 9 are small firms. Therefore, because small firms are just as likely to allocate a large percentage of their gross annual sales towards R&D, they cannot be considered less innovative than the large WWT firms. In addition, the average R&D intensity for small firm respondents was

12.5%, compared with 6.8% for large firms. These results concur with recent work on the innovation system in Ontario, which found that small firms show high rates of R&D intensity, relative to large firms (Gertler and Wolfe 1998).[4]

Table 6.3: R&D Intensity by Firm Size[5]

Count (Row Pct.) (Col. Pct.)	**Small**	**Large**	Row Total
Low	**6** (46.2) (31.6)	**7** (53.8) (41.2)	**13** (36.1)
Medium-Low	**4** (36.4) (21.1)	**6** (63.6) (35.2)	**11** (30.6)
Medium-high	**5** (62.5) (26.3)	**3** (37.5) (17.6)	**8** (22.2)
High	**4** (100.0) (21.1)		**4** (11.1)
Column Total	**19** (52.8)	**17** (47.2)	**36** (100.0)

This result also supports the contention in the innovation literature that small firms make a significant contribution to the innovation process (Britton 1991, MacPherson 1994,

[4] It should be noted that while large firms may indicate lower rates of R&D intensity, the actual dollar contribution can be quite large.
[5] More than 20% of the cells had expected values of less than 5. Nonetheless, a Chi-square test of association between the two variables yielded a statistically insignificant relationship.

Rothwell and Dodgson 1994). Moreover, this literature suggests that their principal contribution is in terms of incremental innovation as opposed to radical innovation. To test this argument, the WWT firms were asked to assign their R&D spending to three categories: the improvement of existing technology; the introduction of entirely new technology; and the customization of existing technology for particular customers. Although categories one and three could be combined under the heading of 'incremental changes in technology' they were separated to differentiate as much as possible between changes which contributed explicitly to the evolution of the technology (first category), and those which were more 'adaptive' in nature. Examples of the latter category included changing the diameter of an inflow pipe to allow it to fit with the customer's existing machinery, or customizing the 'add-ons' to the technology to fit the customer's manufacturing process.

The interviews with the WWT firms revealed that the improvements to existing technology (category one) were not conducted without input from their customers. In fact, many of the improvements made to the technology were customer driven. In one case, a firm which develops and manufactures process-integrated technology and has designed systems principally for the steel industry, is now expanding the application of its technology into other sectors. It is working closely with customers in those sectors to allow their technology to solve their customer's environmental problems. This is deemed to be an improvement in the technology because it extends its capability to cope with a wider range of environmental applications. The knowledge that this firm gains from addressing the requirements of their customer will be incorporated into future technology as a design improvement.

Looking at the structure of R&D spending among WWT firms overall, on average, 52% of R&D spending is allocated towards the improvement of existing technology, 32% is allocated towards the introduction of new technology, and the remaining 16% is allocated towards the customizing of technology for particular customers (Table 6.4). When these proportions are reallocated according to the size of the firm, a similar pattern emerges with both small and large firms allocating, on average, the majority of their R&D spending towards the improvement of existing technology, rather than the introduction of new technology.

Table 6.4: Mean Percentage Allocation of R&D Spending of WWT Firms, by Firm Size (%)

	Small (n=19)	Large (n=17)	All Firms (n=36)
Improvement of Existing Technology	43.2	62.4	52.1
Introduction of New Technology	38.2	24.2	31.8
Customization of Existing Technology for Particular Customers	18.6	13.4	16.1
TOTAL	100.0	100.0	100.0

Source: Survey Data
(Note: Allocations between Large and Small Firms not significantly different; Mann Whitney test, p=0.05)

Therefore, not only does the small firm dominated WWT sub-sector make a significant contribution to the innovation process, but also this contribution is towards incremental innovation rather than new innovation. Consequently, this supports the argument in the innovation literature that some small firms make a significant contribution to the process of innovation through incremental changes in technology, as opposed to the development of 'new' technology. The low percentage of R&D spending allocated towards 'new' technology introduction among large firms (24.2%) indicates that the large firms are not using their technological resources to be leaders in this industry. The explanation lies in the fact that just over half of the large firms are foreign-owned and typically, technological capital will be transferred from the home to the host location. This is addressed more directly following.

6.1.2 Ownership and Innovativeness

With respect to ownership, foreign firms would not be expected to conduct much R&D within the province (Hypothesis 4). Typically, much of their R&D is carried out in their home location, with the host acting as a site for manufacturing and/or distribution. In the case of WWT firms, while the mean R&D intensity for foreign-owned firms is indeed lower than that for Canadian owned firms (6.5% and 9.3% respectively), these are not significantly different.[6] When R&D intensity is disaggregated according to its strength, the majority of both Canadian owned (63%) and foreign-owned (78%) firms fall into the low and medium-low categories (Table 6.5). In contrast, 37% of Canadian owned firms are high or medium-high innovators, compared with only two foreign-owned firms (22%). Collapsing the categories low and medium-low, and medium-high and high, allows this relationship to be tested statistically. The result indicates a statistically insignificant relationship between ownership and R&D intensity (Table 6a, Appendix 6).

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[6] Mann Whitney U test, p=0.05

Table 6.5: R&D Intensity by Firm Ownership

Count (Row Pct.) (Col. Pct.)	**Canadian**	**Foreign**	Row Total
Low	**9** (69.2) (33.3)	**4** (30.8) (44.4)	**13** (36.1)
Medium Low	**8** (72.7) (29.6)	**3** (27.3) (33.3)	**11** (30.6)
Medium-High	**6** (75.0) (22.2)	**2** (25.0) (22.2)	**8** (22.2)
High	**4** (100.0) (14.8)		**4** (11.1)
Column Total	**27** (75.0)	**9** (25.0)	**36** (100.0)

Although statistically, the relationship is insignificant, the fact remains that the majority of the foreign-owned firms are categorized as low or medium-low innovators. Therefore, support for the argument that the R&D function is truncated among foreign-owned firms in Canada seems apparent.[7] While the mean R&D intensity for foreign-owned WWT firms is higher than manufacturing as a whole or machinery in particular (see Figure 6.1), they still report lower R&D intensities than their Canadian competitors. Therefore, their inability to import know-how is similar to many other high technology sectors in Canada.

[7] See Britton and Gilmour 1978, Britton 1996.

When the type of R&D performed by the WWT firms is closely examined, it is found that on average, the majority of R&D performed by foreign firms is for the purpose of improving existing technology rather than for the development of new technology (Table 6.6). Approximately 61% of the R&D spending by foreign firms is allocated towards the continued improvement of existing technology, while only 22% goes towards the introduction of new technology.

Table 6.6: Mean Percentage Allocation of R&D Spending of WWT Firms, by Ownership (%)

	Canadian (n=27)	**Foreign** (n=9)	**All Firms** (N=36)
Improvement of Existing Technology	49.9	61.3	52.1
Introduction of New Technology	34.0	22.4	31.8
Customization of Existing Technology for Particular Customers	16.1	16.3	16.1
TOTAL	100.0	100.0	100.0

Source: Survey Data
(Note: Allocations between Canadian and foreign-firms not significantly different; Mann Whitney test,p=0.05)

Combining the 'Improvement of Existing Technology', and the 'Customization of Existing Technology for Particular Customers' categories, it is found that approximately 78% of the R&D of foreign-owned firms is allocated towards incremental changes in technology (the proportion for Canadian-owned firms is 66%). The focus on incremental innovation among the Ontario branch plants of foreign-owned firms can be explained with reference to some of the observations made in Chapter 5. In particular, as indicated by Tables 5.7 and 5.8, the innovation process among foreign-owned firms was found to be driven by the fact that their customers had to comply with Ontario's environmental regulations. Although many of the water pollution regulations in Ontario have been developed with reference to USEPA requirements, they still differ enough to require the modification of any existing US-developed technology. Consequently, interviews with these foreign firms revealed that the principal reason for modifying their existing technology was to allow it to control or prevent a different range of toxic substances other than those the technology was originally designed for, or to achieve higher rates of pollutant removal.

End-of-pipe technology rather than process-integrated technology was considered, for the purposes of this research, to be the more standardized approach to achieving regulatory compliance. Therefore, firms who specialize in the production of this technology would be expected to be less innovative than firms that specialize in either the production of process-integrated technology, or both types of technology. The survey data revealed however, that firms who specialize in the production of end-of-pipe technology showed similar rates of R&D intensity to firms specializing in the production of process-integrated technology (mean rates of 6.6% and 6.4% respectively).

When the firms are grouped by R&D intensity, it is the Multi-Technology firms that emerge as the most innovative with 3 of 5 firms (60%) reporting a high R&D intensity (Table 6.7). Although more end-of-pipe firms than process-integrated firms are classified as having a low R&D intensity (8 of 18 firms (44%) and 5 of 13 firms (39%) respectively), this result is reversed when the medium-high and high categories are examined. Instead, 6 of 18 end-of-pipe firms (33%) have medium-high or high R&D intensities while only 2 of 13 process-integrated firms (15%) can be classified in this fashion. Consequently, these data indicate that firms producing end-of-pipe technology are no less innovative than firms producing the more technologically advanced process-integrated technologies.

Table 6.7: R&D Intensity by Technology Type

Count (Row Pct.) (Col. Pct.)	**End-of-Pipe**	**Process-integrated**	**Multi-Technology**	Row Total
Low	**8** (61.5) (44.4)	**5** (38.5) (38.5)		**13** (36.1)
Medium Low	**4** (36.4) (22.2)	**6** (54.5) (46.2)	**1** (9.1) (20.0)	**11** (30.6)
Medium-high	**5** (62.5) (27.8)	**2** (25.0) (15.4)	**1** (12.5) (20.0)	**8** (22.2)
High	**1** (25.0) (5.6)		**3** (75.0) (60.0)	**4** (11.1)
Column Total	**18** (50.0)	**13** (36.1)	**5** (13.9)	**36** (100.0)

6.2 The Relationship between Technology Producers and Users.

The analysis presented in Chapter 5 indicated that the impact of environmental regulations on the innovation activity among the WWT firms was channeled through the regulated firms. By compelling the regulated firms to adopt environmental technology, the regulations created a market for water and wastewater technology. This brought the WWT firms and the regulated firms together in a customer-supplier relationship, the nature of which is explored in this section.

6.2.1 The Importance of the Customer Relationship to the WWT Firm's Innovation Strategy

It has been shown previously, that the customers of environmental technology play an important role in stimulating innovation among WWT firms. Nevertheless, these technology suppliers could be focused on producing generic one-size-fits-all solutions. Therefore, in order to explore the strength of this relationship, and how it varies according to firm size, ownership, and technological orientation, the WWT firms were asked to indicate how important they viewed the role of their customers. This question was posed twice - in terms of the development of the specific technologies they listed (Question 12), and also in terms of their innovation strategy overall (Question 28).

As indicated in Table 5.3 Chapter 5, 94% of the WWT firms deemed the customer to play an important role in their innovation strategy, with the majority of firms (66%) indicating a 'very important' role. A similar pattern emerges when the importance of the customer-supplier relationship in the development of the specific technologies listed by the WWT firms is examined (Question 12). Here, in 97% of the technological cases, the customer-supplier relationship was deemed to be important (Table 6.8).

Table 6.8: Importance of the Customer Relationship to the Development of the Technologies listed by the WWT Firms

	FREQUENCY (Number of Technologies)	PERCENTAGE
Not Important	2	2.5
Moderately Important	41	50.6
Very Important	38	46.9
Total	81	100

Source: Survey Data

Reconfiguring the data to account for the differences in firm size, ownership and technological orientation, yields a similar pattern of results (Tables 6b, 6c, and 6d respectively, Appendix 6). Collectively, these results indicate that the WWT firms view their relationship with their customers as an essential component, not only in the development of individual technologies, but also in how they organize their innovation strategy overall.[8]

6.2.2 The Customer and the Type of Production Followed by the WWT Firm

Although the results reported above illustrate that the customer-supplier relationship is an important facet of the environmental-innovation model, it is necessary to take apart this relationship in order to completely understand its role. Question 18 of the survey questionnaire asked the WWT firms to specify how they organized their production activity in terms of one-at-a-time, small batch runs, and long production runs. The results indicate

[8] Theoretical support for the importance of the customer-supplier relationship the innovation process can be found in the work of Lundvall (1988), Rothwell (1994a), Shaw (1994), Riggs and von Hippel

how close is their relationship with their customers. Firms who mainly developed technologies 'one-at-a-time to customer's orders' enjoy a closer, more interactive customer-supplier relationship than those mainly producing technology in long production runs, or even in small batches. As innovation is an iterative and maybe an interactive process (Rothwell and Zegveld 1985, Kline and Rosenberg 1986), the more customized the technology is, the greater the level of interaction between the parties in the innovation relationship. Conversely, the more standardized the technology is, the more it is likely to be produced in long production runs, and supplied in an off-the-shelf or arm's length fashion. Therefore, supplier-customer interaction would be minimal.

The WWT firms produce just over 50% of their technology on a one-at-a-time basis (Table 6.9) followed by 27% in small batch runs, and 23% in long production runs. Therefore, with 77% of production occurring on a one-off basis or at the very most in small batches, it is clear that the WWT firms enjoy a strongly interactive relationship with their customers. The pattern is repeated when the firms are disaggregated according to size (Table 6.9), and according to ownership (Table 6e, Appendix 6).

(1994), Fagerberg (1995), Hutcheson, Pearson, and Ball (1996) and Gertler and Digiovanna (1997).

Table 6.9: Mean Percentage Allocation of Production of WWT Firms, by Firm Size (%)

Production	Small (n=19)	Large (n=17)	All Firms (n=36)
One-at-a-Time to Customer's Orders	50.7	50.8	50.6
Small Batch Production	28.7	23.9	26.8
Long Production Runs	20.5	25.2	22.5
TOTAL	100.0	100.0	100.0

Source: Survey Data
(Note: Allocations between Large and Small Firms not significantly different; Mann Whitney test, p=0.05)

In both the 'Ownership' and 'Size' disaggregations, there was a slightly higher allocation towards long production runs over small batch production among foreign-owned firms and large firms, respectively (although statistically, the differences are not significant). This can be explained by the fact that two of the large foreign-owned firms produced almost 100% each, of their output in a long production run. In one case, the firm was supplying a standardized end-of-pipe technology, in the other, the firm was described as a multitechnology firm. However, in the latter case, much of the production was geared towards end-of-pipe technology rather than process-integrated technology.

When the data are disaggregated according to technology type, the expectations regarding the organization of production and the type of technology produced by the firm don't hold true as shown by the statistically insignificant test results (Table 6.10). In each of the three types of firm, technology is produced mainly on a one-at-a-time basis. This is most pronounced in the case of process-integrated technology firms, where 62% of their production is carried out in this way. Process-integrated technologies are the more complex approach to regulatory compliance and hence, are more cutting-edge in their design. Consequently, they are produced with an extremely high level of individual customization, which helps explain why the process-integrated technology firms gear the greater part of their production towards one-at a-time type of activity.

Table 6.10: Mean Percentage Allocation of Production by WWT Firms, by Technology Type (%)

Production	End-of-Pipe (n=18)	Process-integrated (n=13)	Multi-Technology (n=5)	All Firms (N=36)
One-at-a-Time to Customer's Orders	44.4	61.9	45.0	50.6
Small Batch Production	29.1	25.9	21.0	26.8
Long Production Runs	26.4	12.1	34.0	22.5
TOTAL	100.0	100.0	100.0	100.0

Source: Survey Data
(Note: Allocations between Technology Types not significantly different; Kruskal-Wallis test, p=0.05)

While the process-integrated technology firms produce more of their technology in a one-at-a-time fashion, it is not the case that the end-of-pipe technology producers produce solely in long production runs. In fact, the greatest share of their production (44%) is also carried out on a one-at-a-time basis. This is followed by small batch production (29%) and long production runs (26%). Interviews with the end-of-pipe technology manufacturers revealed that this particular technological approach to achieving regulatory compliance, although considered the least complex or cutting edge by the regulatory agencies, does not necessarily imply that the technology itself has reached the end of its product life cycle. In some cases the technologies are quite sophisticated pieces of engineering, requiring a fair degree of customization in order to allow a fit with the customer's existing production machinery. They are not all simply supplied on an off-the-shelf basis and installed with the minimum of trouble.

6.2.3 The Timing of Customer Input in the Innovation Process

The data reported above illustrate that the WWT firms and their customers are involved in more than the arm's length supply relationship suggested by Ashford (1994). Instead, the relationship is focused on the customization of specific water and wastewater technology to meet the compliance needs of individual firms. Consequently, there is an interdependent relationship between the producers of the technology and their customers. The industrial innovation literature (for example, Rothwell 1990, 1994a and b, and Rothwell and Dodgson 1991) strongly implies that the most successful technology producers will experience a strong, communication-intensive relationship with their customers. While these flows of information are important at the production stage of the technology and beyond, they are of crucial importance at the design phase of the innovation process. This is especially the case with small firms who may be limited in their technological and design expertise.

This argument regarding the importance of information flows between technology producers and their customers at the design and engineering phase of the innovation process holds in the development of water and wastewater technology. The WWT firms were asked in the survey questionnaire (Question 11), to indicate the point in the innovation process they first received input from their customers. In 67% of the technologies produced by the WWT firms, input was received at the design and engineering phase, while in 22% of cases the input occurred at the earlier basic research stage, and in only 11% of cases did it occur at the later marketing phase of the innovation process (Table 6.11).

Table 6.11: Timing of Customer Input by Firm Size (number of technologies produced)

Count (Row Pct.) (Col. Pct.)	**Small**	**Large**	**Row Total**
Basic Research	**11** (61.1) (26.2)	**7** (38.9) (17.9)	**18** (22.2)
Design and Engineering	**30** (55.6) (71.4)	**24** (44.4) (61.5)	**54** (66.7)
Marketing	**1** (11.1) (2.4)	**8** (88.9) (20.5)	**9** (11.1)
Column Total	**42** (51.9)	**39** (58.1)	**81** (100.0)

Chi-Square = 6.898	DF = 2	P = .032

Clearly, these data indicate that co-operation between suppliers and their customers is more important in the early applied phases of the innovation process. The result holds true when the timing of the customer input is explored among firms of different size categories. Among technologies produced by small firms, 71% were developed with customer input first occurring at the applied design and engineering phase, while the same occurred in 62% of technologies produced by large firms. Again, this attests to the importance of co-operation in the early phases of the innovation process.

In terms of WWT firms co-operating with their customers at the basic research or earliest phase of the innovation process, this occurred in 26% of the small firm developed technologies and 18% of the large firm developed technologies. A closer inspection of the small firms producing these technologies revealed that they collaborated with their customers at this very early stage because the costs associated with this initial phase were significantly higher than those associated with the applied phase. The reason lay in the specialized nature of the technical information required, particularly regarding the nature of the customer's production process. Because the small firms were not able to absorb the risk of performing basic research, the customer fulfilled this role as a basic research provider.

The co-operation between the producer and the user of technology is argued to be more crucial in the early phase of innovation, especially when the technology is considered to be more complex in form (Lundvall 1988, Gertler 1993, 1995). However, in the case of water and wastewater technology, the early phase co-operation is eclipsed by design and engineering. Approximately 77% of end-of-pipe technologies were developed with the customer-supplier relationship first taking place at the design and engineering phase of the innovation process, while this occurred in 51% of process-integrated technologies (Table 6.12). The reason is that there is limited basic research, minimizing its importance among Ontario firms, while local customization is needed to some extent.

Table 6.12: Customer Input by Technology Type (number of technologies produced)

	End-of-Pipe	Process-integrated	Row Total
Basic Research	**9** (50.0) (18.8)	**9** (50.0) (27.3)	**18** (22.2)
Design and Engineering	**37** (68.5) (77.1)	**17** (31.5) (51.5)	**54** (66.7)
Marketing	**2** (22.2) (4.21)	**7** (77.8) (21.2)	**9** (11.1)
Column Total	**48** (59.3)	**33** (40.7)	**81** (100.0)

Chi-Square = 7.670	DF = 2	P = .022

These data also show the occurrence of a later phase relationship between the customer and the supplier in the production of process-integrated technology. Although only 21% of process-integrated technologies were produced with the customer providing marketing assistance, this is still substantially greater than the corresponding percentage for end-of-pipe technology. A closer inspection of the data, with support from personal interviews, reveals that the firms producing these particular process-integrated technologies are foreign-owned, and their customers provide a distribution channel for their technology within the Canadian market. The customer firms are either the branch plants of US owned multinational firms who have a similar, existing relationship with the WWT firm in the US, or they are branches of Canadian owned multilocational firms. In the latter case, the technology is distributed to other branches of the customer firm across Canada.

6.2.4 The Role of Strategic Alliances in the Innovation Process

Strategic Alliances, as a conduit for co-operation between suppliers and customers of environmental technology are not universal among water and wastewater technology firms. Nevertheless, 39% of firms reported that strategic alliances were an important part of their technological strategy (Table 6.13).[9] This figure was evenly distributed among large and small firms.

Table 6.13:Importance of Strategic Alliances by Firm Size

Count (Row Pct.) (Col. Pct.)	**Small**	**Large**	Row Total
Important	7 (50.0) (36.8)	7 (50.0) (41.2)	14 (38.9)
Not Important	12 (54.5) (63.2)	10 (45.5) (58.8)	22 (61.1)
Column Total	19 (52.8)	17 (47.2.)	36 (100.0)

Chi-Square = .071	DF = 1	P = .790

[9] These data were generated from the written responses to Question 16 of the survey, Appendix 4.

In general, firms enter into strategic alliances to share the risks of technology development, to gain access to resources including technology and managerial skills, or to enter foreign markets (Hagedoorn and Shakenraad 1990, Mytelka 1991, Hagedoorn 1995). Ahern (1993) argues that, although a risky venture which can sometimes result in the firm being taken over by the partner, strategic alliances are an important method through which small R&D intensive Canadian firms can gain access to foreign markets. Given the limited size of the Canadian market for environmental technology, small WWT firms would be expected to view strategic alliances as an important competitive strategy, granting them access to markets outside of Canada (Hypothesis 5). However, as reported in Table 6.14, the majority of Canadian owned firms (63%) reported that strategic alliances were not an important aspect of their competitive strategy.

Table 6.14:Importance of Strategic Alliances by Firm Ownership

Count (Row Pct.) (Col. Pct.)	**Canadian**	**Foreign**	Row Total
Important	**10** (71.4) (37.0)	**4** (28.6) (44.4)	**14** (38.9)
Not Important	**17** (77.3) (63.0)	**5** (22.7) (55.6)	**22** (61.1)
Column Total	**27** (75.0)	**9** (25.0.)	**36** (100.0)

Chi-Square = .156	DF = 1	P = .712

Table 6.14 also indicates that no statistically significant relationship exists between the ownership of the WWT firms and the importance of strategic alliances ($p=.712$). Consequently, Canadian owned firms are no more likely to view strategic alliances as an important part of their competitive strategy than foreign firms are. In each of the fourteen cases citing the importance of alliances, the principal reason given for adopting that approach was to access international markets (the Canadian market in the case of the foreign-owned firms). Generally, these alliances took the form of technological agreements with the suppliers of industrial machinery who incorporated the water and wastewater technology into their product technology. Examples of this include the incorporation of copper recovery systems into circuit board manufacturing technology, or the use of chrome purification systems in oil drilling machinery manufacture, or chrome manufacturing technology. In each of these examples, the water and wastewater technology customer was based outside of the home location of the supplier.

6.2.5 Role of External Sources of Technical and Professional Support

In order to better understand the organization of the innovation process underlying the development of water and wastewater technology, the respondents were asked to evaluate the role of a number of external sources of technical and professional expertise on their technological strategy (Question 28). As noted in Chapter 3, the innovation process is transactional in nature, with the transactions occurring either internally within the firm, externally at arm's length in the market, or externally in some hybrid relationship where some degree of co-operation is involved. By asking the WWT firms to measure the importance of each source of outside technical and professional expertise the organization of these transactions could be established. This would provide valuable information about how the WWT firms organized the technological links in their production chain. The data generated by the questionnaire are reported in Table 6.15.

Table 6.15: Importance of External Sources of Technical/Professional Support[10]

Source of External Support	Important %	Not Important %	Mean Rank
Private Industrial Design Services	31.4	68.6	1.43
Private R&D Services	22.9	77.1	1.26
Private Engineering Services	54.3	44.4	1.91
Testing Laboratories	42.9	57.1	1.91
Government Research Programs	42.9	57.1	1.91
Government Research Services	34.3	65.7	1.69
Ontario Centre for Environmental Technology Advancement (OCETA)	11.4	88.6	1.23
Market Research Consultants	54.3	45.7	1.94
Distributors	34.3	65.7	1.88
Universities	65.7	34.3	2.14
Suppliers	65.7	34.3	2.60
Customers	94.3	5.7	3.65

Source: Survey Data

[10] The firms ranked the importance of each source of external support on a scale ranging from "1=not important" through to "5=critically important". For this table the different measures of importance (ranks 2-5) were aggregated to "% important".

The first four categories of support listed in Table 6.15 refer to private sources of technical expertise, ranging from basic research (private R&D) through to engineering and testing. The majority of WWT firms indicated that these external sources of support (with the exception of private engineering services) were not important to their technological strategy overall. In the case of private engineering services, these were determined to be environmental engineering consulting firms providing information regarding the technical specifications of the environmental regulations.

The federal and provincial governments provided the next three categories of support. The first of these categories refers to a range of government programmes designed to promote the development and growth of the environmental industry sector, through the use of financial instruments (see Table 6f, Appendix 6). The next category concerns a variety of government services designed to provide technical and commercial support for Canadian firms, including environmental technology firms. Included are the following: the National Research Council (NRC) which provides basic research and engineering expertise to firms; the Institute for Environmental Research and Technology (IERT) which is under the umbrella of the NRC, and provides scientific and technical assistance to firms, as well as licensing IERT developed technology to firms for commercialization; Environment Canada's Wastewater Technology Centre which conducts research and provides technical and scientific expertise to water and wastewater technology firms; and the Province of Ontario's Green Industry Office, which provides business development, market intelligence, and export advice to Ontario environmental firms. The last category of government support is the Ontario Centre for Environmental Technology Advancement (OCETA). This is the Ontario branch of the Federally and Provincially funded network of Canadian Environmental

Technology Advancement Centres (CETACs). Their mandate is to provide technical and business development assistance to environmental technology firms.

Despite the variety of government programs and services available, they don't figure strongly in the technological strategies of the WWT firms. While many firms take advantage of them, they are at best only of moderate importance as illustrated by the highest mean ranking of 1.91 (government research programmes).

Of the remaining categories of technical and professional support, all except 'Distributors' were deemed to be of importance to the WWT firms. In particular, customers play an extremely important role as sources of technical and professional support with 94% of firms deeming them to be important. This is followed by both universities and suppliers where 65% of the WWT firms considered them to be important. Both also received a high mean ranking indicating that their level of importance was scored towards the higher end of the scale provided.

Tables 6g and 6h (Appendix 6) disaggregate these data according to the size of the firm, and the firm's technological orientation. Small WWT firms appear to place a greater importance in accessing external sources of technical and professional support, than large firms (Table 6f). In all categories of support, apart from 'universities', they indicated a mean rank higher than the average for all firms. Their highest scores (indicating a higher level of importance) were not clustered in one area of support, instead they cut across the spectrum of the innovation process from engineering support through to marketing and distribution support. Structurally, given the small size of the small firms (see Chapter 4), many find it expedient and necessary to rely on external sources for inputs of technical knowledge and marketing expertise. They face difficulties due to the constraints of size in acquiring information regarding the nature of the environmental regulations, the technical information necessary to allow them to produce compliance technologies, and finally the information regarding the market for water and wastewater technology. Many of the small firms interviewed stated that the principal reason for accessing the external sources of technical support was the specialized nature the technology being developed. They recognized their own internal knowledge capabilities could only take them so far down the technology development path. Engineering consultants, who had expertise in specific areas of water and wastewater technology, would allow them to extend their capabilities. Government research services were used for the same reason. In one case, a firm was involved in a joint product development agreement with the Pulp and Paper Research Institute of Canada (PAPRICAN) to extend the capability of their technology to address specific pollution problems experienced by the pulp and paper industry. In other cases, the small firms used engineering service firms to gather technical knowledge on the requirements of the environmental regulations.

When the data are disaggregated by the technological orientation of the firms, it is the Multi-Technology firms that place the greatest importance on external sources of technical and professional expertise (Table 6g). In all categories, except for suppliers and customers, they have the highest mean scores. As the majority of Multi-Technology firms are small, their mean scores are consistent with those of small firms as a whole. In common with other small firms, they have high rates of R&D intensity (see Tables 6.2 and 6.6 above). Therefore, the WWT firms that utilize external sources of technical and professional support the most are also the ones who have consistently high rates of R&D intensity and are thus considered to be the most innovative. This result supports earlier studies of the relationship between innovativeness and the use of external sources of support. MacPherson (1988, 1992) for example, found that innovative small firms procure external producer services on a regular basis, and that the level of procurement was highly positively related to their level of innovation. In the case of the WWT firms, it is apparent that the establishment of external technical linkages has overcome in-house limitations in scientific and technical knowledge.

The ability of the Multi-Technology firms to compete successfully within two different technological markets attests to their flexibility, despite the limitation of their size. In terms of the technologies they produce, the end-of-pipe technologies are incorporated into their process-integrated technological systems giving an internal complementarity of technologies. This complementary nature of their technology allows the firm the flexibility to produce in two technological markets. In addition, their flexibility is also derived from their ability to achieve economies of scope through the use of external sources of technical and professional expertise (Storper and Walker 1989, Scott 1992).

The process-integrated firms have mean scores less than the average for the entire sample, in all categories except 'universities'. More of the firms manufacturing this type of water and wastewater technology are large, and typically, large firms place less of an importance on external sources of expertise. Due to their size, they are better able to absorb the transactions costs associated with technology development. However, given the advanced nature of the technology they are developing they do maintain strong links with the sources of high quality technical and scientific information the universities can provide. In many cases, these links have been maintained since the inception of the firm due to the fact the CEO was a former engineering graduate student. For example, Zenon, which is one of the largest Canadian owned water and wastewater technology firms originated from McMaster

University, and continues to maintain strong links with that university. Similarly, the CEO of a large Canadian owned firm manufacturing process-integrated technology, maintains close links with the Faculty of Engineering at the University of Toronto because of the specialized technical knowledge available, and because he earned his Ph.D. there.

6.3 Discussion of the Organization of the Innovation Process

Collectively, the results reported in this chapter provide some important insights into how the production of water and wastewater technology is organized. First, the relationship that exists between the WWT firms and their customers is centered on the development of custom-made technologies. As indicated by Tables 6.9, 6.10, and 6e (Appendix 6), WWT firms produce most of their technology in a 'one-at-a-time' fashion, for individual customers. This suggests a high level of interaction between both actors in the innovation process. Further support for this high level of interaction is drawn from Tables 6.11 and 6.12, where the WWT firms reported that they received input from their customers early on in the innovation process.

Under Hypothesis 6, the WWT firms specializing in the development of process-integrated technologies were expected to experience a greater level of interaction with their customers. This expectation was based on the fact that the technology was assumed to be more complex and as Lundvall (1988) and Gertler (1993, 1995) note, co-operation between firms is stronger under this condition. However, co-operative relationships between the WWT firms and their customers are just as strong for end-of-pipe technology manufacture as they are for process-integrated technology. In addition, while interaction between the WWT firms and their customers occurred early on in the innovation process, it was not more likely to occur with the development of process-integrated technology than end-of-pipe technology. Therefore these results are applicable to all WWT firms regardless of their size, ownership and technological orientation, and as such Hypothesis 6 does not hold.

The relationship between the WWT firms and the customer firm is continuous, not ending with the installation of the technology. As indicated by Tables 6.4 and 6.6, the WWT firms irrespective of their size or ownership focus their innovation efforts on incremental changes in their technology rather than the introduction of new technologies. This commitment towards incremental innovation is driven by the relationship with their customers. All of the WWT firms interviewed indicated that their customers relied on them for technical assistance during the installation of the technology and beyond as the technology was used. Through continued use, information was generated regarding the capabilities of the technology, and this knowledge was used to formulate design and engineering improvements. As shown in Table 6.6, this continual process of improvement in the technology, driven by the interactive customer relationship, occurred just as much with foreign-owned firms as Canadian owned firms. Therefore, it is not the case as stated under Hypothesis 4, that foreign-owned firms merely distribute foreign designed technology in Ontario. Instead they enjoy just as much a collaborative relationship with domestic (Canadian) users of the technology as Canadian owned firms do. In similar fashion, the Canadian owned firms who operate in international markets also co-operate with their international customers in the development of technology to suit their specific requirements. In one particular case, a large Canadian firm was developing a chemical recovery system for a large European aerospace manufacturing plant. Although based on a proprietary technology manufactured by the firm, it still required significant redesign and engineering, not only to fit with the aerospace manufacturer's production process but also to allow it to fit the compliance requirements of the country in which the plant was located.

In common with all of the firms interviewed, the overlying reason for the collaborative relationship between the WWT firms and their customers was due to the specialized nature of the water and wastewater technology. Even in cases where the firm produced technology in long production runs, a certain degree of customization was required prior to its installation in the customer firm. In all cases, the WWT firms reported that a close relationship was necessary to allow their technology to achieve a good fit with their customer's production process. While the WWT firms have the knowledge regarding the capability of their particular technology, they don't have the knowledge regarding the customer's production process. Therefore, both actors in the innovation process possess specialized knowledge that is complementary. This supports the argument made by Teece (1986), Rothwell (1994a), and Freeman and Soete (1997) among others that innovation is most successful in an environment where a complementarity of knowledge exists between firms, particularly where firms are in a supplier-user relationship. The customer also fulfills an important role as a provider of information on the technical requirements of the environmental regulation. The regulatory agencies do not explicitly provide such information to the environmental technology firms, leaving each individual firm to find that information themselves[11]. Because the WWT firms require information regarding the technical needs of the environmental regulations and the nature of the customer's production process, and the customer requires

[11] Recently, under Ontario's Environmental Bill of Rights, the Environmental Commissioner's Office designed an internet web site which among other things lists proposed changes to environmental regulations. The onus is still on the WWT firm to access this site to discover any impending

information on the technological capabilities of the compliance technology, a communications rich relationship exists between the firms.

Because water and wastewater technology is very specialized, and produced to fit the requirements of individual customers, the transactions costs associated with their development can be high. There are costs associated with obtaining the specialized knowledge inputs that are required to develop these technologies. Consequently many firms will rely on external sources, usually in the form of environmental engineering consultants and universities, for this specialized technical knowledge. Although the firms didn't refer to transaction costs per se, they did admit that they used external producer services and universities as key sources of technical information because it was more efficient for them to do so. The costs of obtaining that information themselves would have been significant and would have slowed their technology development process. Small firms in particular have successfully used external sources of expertise as part of their innovation strategy.

Hypothesis 7 held that the process-integrated technology firms would hold locational proximity to their customers as an important factor in the successful development of their technology.[12] Conversely, the end-of-pipe technology firms would view this as not being important. The question of the importance of proximity between actors in the innovation process is drawn from a number of sources. Storper (1992) argues that the trend towards flexible production has created strong linkages between spatially concentrated interdependent producers where the density of inter-firm relationships and the frequency of interaction

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regulatory changes.

[12] Although not tested statistically, this hypothesis was examined through the interviews with the WWT firms and the users of water and wastewater technology.

influence the level of innovativeness. Information and knowledge exchanges, which are necessary to overcome the uncertainty associated with technology development and adoption, are made easier when firms are in close proximity. Gertler (1993, 1995) echoes this point arguing that the level of personal interaction between producers and users is in part, a function of distance. As distance between firms increases, the level of personal interaction declines. Porter (1990) posits that competitive advantage is derived regionally, stating "The process of creating true competitive advantage is localized and benefits greatly from the proximity of lead customers, suppliers, educational institutions and rivals". In the case of the WWT firms interviewed, the question of proximity to the customer is still unresolved regardless of the technology the firms are manufacturing. On the one hand, much of the supplier-customer relations with respect to the development of water and wastewater technology take place within Ontario. The largest concentration of WWT firms in Canada is located there, as are many of the external sources of technical expertise. On the other hand, a number of firms collaborate technologically with customers who are located both out of province and internationally. In those cases, the firms stated that their ability to innovate was in no way diminished by the physical distance from their customers, even in cases where they were developing process-integrated technologies. They did admit however, that bi-weekly or monthly meetings with their customers were an important part of their innovation process. As such, it is still an open question as to how important locational proximity is.

Incorporated into the literature citing the importance of locational proximity between firms in the innovation process is the concept of trust. As firms are adopting more flexible forms of production organization where inter-firms relations are strong, the notion of trust underlying these relations has become a topic of debate. Harrison (1992) suggests that locational proximity between firms may increase interaction that in turn generates trust and further collaboration. Saxenian (1990, 1994), who, in citing examples from Silicon Valley, argues that trust between firms is important in the innovation process supports this argument. There, small electronics firms have succeeded in building informal supplier and customer-networks, where information and knowledge sharing is trust based. While more trust based relations between firms may be evident in some sectors for example microelectronics, computing, and telecommunications (Saxenian 1990, 1994, Angel 1994), they are not particularly evident in the development of water and wastewater technology. Although the WWT firms co-operate quite extensively with their customers, with this co-operation lasting well beyond the installation of the technology, the relations are always contractually based rather than trust based. As one firm put it *"It is always easier to trust who you are dealing with when there is a contract signed"* The principle reason why the relations are defined under contracts is to protect the WWT from opportunistic behaviour by their customer. This supports Burchell and Wilkinson (1998) and Arrighetti, Bachman, and Deakin (1998), who argue that contracts act to formalize or underpin trust based relations between firms.

Typically, the WWT firm, because of the specialized nature of the technology they are developing, will insist the customer signs a confidentiality agreement. Each technological solution that is developed is done so for each individual customer, therefore and in order to protect against technological leakage, a confidentiality agreement is signed. Even though both firms share knowledge and information, ownership always remains in the hands of the WWT firm. The comment "*we own it, but it is for their problem*", is common among all the firms interviewed. Given the nature of the technology, the fear of opportunistic behaviour is quite strong.

There is also a need to protect the WWT firm's technological capital because of the nature of the market for water and wastewater technology. This can best be described as a niche market. The niches are based on the technological approach used to prevent and control water and wastewater. For example, two of the biggest firms, Zenon and Trojan Technologies would not compete against one another although they are manufacturing pollution prevention technologies. Trojan's approach is to use UV radiation, while Zenon manufactures systems based on membrane technology. These two approaches are not interchangeable, and are customized for particular industrial firms and sectors. Within each of these technology-based niches, few competitors exist.

When the results presented in this chapter are examined collectively, a picture of the WWT firms emerges. They are innovative (as shown by their R&D intensity), their technological output is focused on custom designed technology, they co-operate closely with their customers in the development of that technology, and this co-operation is based on a complementarity of knowledge. Consequently, they are an example of what Pavitt (1984) calls a 'specialized supplier'. These firms, which tend to be the producers of highly specialized technology, produce customized technology in close co-operation with their customers. The classification of the WWT firms as 'specialized suppliers' is relevant for all firms regardless of size, ownership and technological orientation.

While it is important to examine the innovation characteristics of the WWT firms collectively, it is also important to examine if these characteristics vary according to the R&D intensity group the firm belongs to. As indicated by Table 6.2, the WWT firms can be classified under four groups according to the proportion of revenue they spend on research and development. The four groups can be labeled as follows: group A (1-5%); group B (6-

9%); group C (10-14%); and group D (>15%). (the structural characteristics for each of these four groups are given in Tables 6i-6l, Appendix 6).

In order to examine whether the four groups of firms differed, a Kruskal-Wallis 1 way ANOVA test was conducted on a variety of innovation characteristics, the results of which are given in the right column of Table 6.16. Although for the most part, the firms do not differ significantly with respect to these characteristics, the following were found to be significant: the proportion of R&D spending allocated towards technology customization; the importance of private R&D services; the importance of both government research programs and research services; and the importance of distributors in the firm's innovation strategy. Therefore, it is these characteristics that can be used as initial indicators of the difference between the groups of firms. Because the Kruskal-Wallis test indicated that at least one of the four groups of firms differed significantly, a further testing procedure was undertaken. This involved a series of Mann Whitney U tests on pairs of R&D intensity groups, the results of which are reported in Table 6.17.

Table 6.16: Selected Characteristics of WWT Firms, disaggregated by R&D Intensity Group (Mean Scores)

Characteristic	A	B	C	D	Significance
R&D for Improvement of Existing Technology (%)	51.4	60.0	60.6	25	No
R&D for Introduction of New Technology (%)	31.6	34.0	21.3	52.5	No
R&D for Customization of Existing Technology (%)	17	6.0	18.1	22.5	Yes
One-at-a-Time Production (%)	50.8	59.5	30.0	65	No
Small Batch Run Production (%)	20.7	28.5	39.2	20	No
Long Production Runs (%)	28.5	12.0	30.7	15	No
Private Industrial Design Services	1.54	1.1	1.25	2.25	No
Private R&D Services	1.07	1.3	1.25	2.0	Yes
Private Engineering Services	1.85	1.8	1.62	3.0	No
Testing Laboratories	2.0	1.91	1.5	2.5	No
Government Research Programs	1.38	1.7	2.37	3.25	Yes
Government Research Services	1.07	1.63	2.0	3.25	Yes
OCETA	1.5	1.3	1.0	1.75	No
Market Research Consultants	1.92	2.0	1.62	2.5	No
Distributors	1.53	1.7	1.62	3.75	Yes
Universities	1.92	1.9	2.62	2.5	No
Suppliers	2.61	2.8	1.87	3.5	No
Customers	3.15	4.1	3.75	3.75	No

Source: Survey Data

Table 6.17: Selected Characteristics of WWT Firms: Difference of Summed Rank Tests for R&D Intensity Groups

Characteristic	A – B	A - C	A - D	B - C	B - D	C – D
R&D for Improvement of Existing Technology (%)						X
R&D for Introduction of New Technology (%)					X	
R&D for Customization of Existing Technology (%)	X			X	X	
One-at-a-Time Production (%)						
Small Batch Run Production (%)						
Long Production Runs (%)						
Private Industrial Design Services					X	
Private R&D Services			X		X	X
Private Engineering Services			X			X
Testing Laboratories						
Government Research Programs			X		X	
Government Research Services		X	X		X	
OCETA						
Market Research Consultants						
Distributors			X		X	X
Universities						
Suppliers						X
Customers						

Source: Survey Data. Note: **X** denotes significantly different groups (Mann Whitney U test, $p = 0.05$)

Taking the data shown in Table 6.17 together, the firms in group D emerge as being significantly different from the other three groups. The firms in the low and medium-low categories (groups A and B) are not significantly different from one another except for the characteristic 'R&D for the Customization of New Technology'. This difference is due to the fact that firms in group B allocate the least amount of R&D spending towards customized technology. The largest proportion of their R&D spending is allocated instead to the improvement of existing technology. Both groups A and B contain more large firms, and they have similar proportions of large and small firms in addition to Canadian and foreign-owned firms. They allocate the largest share of their R&D spending to incremental changes in technology rather than the development of new technology, and their production is mainly geared towards custom made technology or small batch production. Furthermore, the majority of firms in both of these groups do not view strategic alliances as being an important part of their competitive strategy. Finally, they show no significant difference in how they rate the importance of external sources of technical and professional expertise.

Crossing the threshold between low R&D intensities and high R&D intensities, the firms in the medium-high grouping (group C) are mainly small and Canadian owned. Like groups A and B, these firms allocate most of their R&D expenditures to incremental changes in technology, but unlike groups A and B, their production is organized almost evenly among the three production categories. However, the pairwise Mann Whitney tests indicate no significant difference between the groups with respect to this latter characteristic. Group C firms differ significantly from the firms in groups A with respect to the importance of government services as a source of technical expertise. The reason for this is the small firms in this group place a slightly higher level of importance on this characteristic, than the firms in group A. In general, the firms in group C tend to indicate a similar pattern of innovation organization despite the higher level of R&D intensity.

Moving to the highest category of R&D intensity, the firms in group D are the most significantly different from all other groups. Although consisting of only four firms, they are exclusively small and Canadian owned. They are also predominantly Multi-Technology firms. While their production is geared towards customized technologies, as is the case with the three other groups, the largest proportion of their R&D spending is allocated towards the development of new technologies rather than the improvement of existing technology. Consequently they are the most aggressive innovators of all the four categories of firms. The group D firms differ significantly from the other three groups with respect to the importance of external technical and professional expertise. In all of the categories of external expertise they indicate higher ranks than the mean rank for all firms taken together. In particular, they consider external technical services as being an extremely important part of their technological strategy. Although these firms are small, they have successfully used these external services as sources of technical knowledge; as important sources of financial capital in the case of government programs; and finally as distribution channels for their technology. Consequently, these external sources or technical and professional expertise are fundamental to all facets of their innovation process.

Although the WWT firms can be viewed collectively as specialized suppliers, there are important differences between the firms when grouped according to their R&D intensity. When viewed in this fashion, the low and medium-low intensity firms are the most similar. To this can be added the medium-high firms who, although comprising a greater frequency of small firms, show more points of similarity with the lower intensity groups than points of dissimilarity. Finally, the high R&D intensity group is the most dissimilar from the other three. Although small firms, they are the most aggressive innovators, with their success largely a result of their use of external technical and professional services. This has allowed them to lower the transactions costs associated with the development of technology.

When the WWT firms are grouped according to their R&D intensity, the end result is three groups which look the same, and one group that is different from all of the others. This analysis imposes some order on the firms that in reality, is not there when the characteristics of individual firms are examined. For example, although R&D intensity groups A, B, and C can be grouped together, the individual firms within them can vary substantially in their use of private and government technical services, their size, and their ownership. Therefore, to use R&D intensity as a grouping variable fails to capture the true picture of inter-firm variability in this industry sub-sector.

A different picture of these firms emerges when we examining the characteristics of individual firms. A close inspection of the firms characteristics, supported by a Hierarchical Cluster Analysis, results in the emergence of three groups, the *predominant* structural characteristics of which are shown in Table 6.18.[13]

[13] The algorithm used to sort the firms in SPSS was nearest neighbour sorting based on Euclidean distance. This method is appropriate when using binary data. The firm characteristics (size, ownership, and external sources of technical/professional support) were converted to a binary scale. The number of firms in each group showing the group characteristics are: Grp.1-11 of 14, Grp. 2-5 of 6, Grp. 3- 10 of 16.

Table 6.18: Predominant Structural Characteristics of WWT Firm Groupings

	Group 1 (n=14)	Group 2 (n=6)	Group 3 (n=16)
Size	Small	Small	Large
Technology Type	End-of-Pipe	Multi-Technology	Process-integrated
Ownership	Canadian	Canadian	Canadian/Foreign
R&D Range	1% - 15%	11% - 40%	1 - 10%
Mean R&D	9%	25%	6%

Source: Survey Data

Group 1

These firms are predominantly small, Canadian owned, end-of-pipe technology manufacturers. Although they spend, on average, 9% of their gross annual sales on R&D, individual firms vary widely in their R&D allocation. As a group, these firms will source scientific and technical expertise from private service firms particularly from engineering firms and testing laboratories, reflecting the incremental nature of their technological activity. They appear to be able to substitute private sources of expertise for government sources. While government technical services are deemed not to be important, these firms instead view government financial programs as an important part of their technological strategy. For this group of firms, government fulfills the role of a provider of financial capital rather than technical or knowledge capital.

Group 2

The second group of firms to emerge is similar to the group D firms of the previous analysis in that they are predominantly small Canadian owned multi-technology firms. They allocate, on average 25% of sales towards R&D, yet firms vary in their individual allocations from 11% up to 40%. Therefore, based on R&D intensity, they are the most innovative of all the water and wastewater technology firms. While the small end-of-pipe firms use private sources of scientific and technical expertise solely, the group 2 firms interface with all sources, government and private. This includes engineering services, testing laboratories and government research laboratories. In addition, they draw on government programs for financial support, and universities play an important role as providers of scientific knowledge. Interestingly, and unlike that of groups one or three, the group two firms do not emphasize their relationship with their customers as being an important part in their technological strategy. Although technologies are not supplied in an arm's length fashion and co-operation with the customer occurs, overall it is not considered to be as important as it is in the case of the group one or group three firms.

Group 3

The last group of firms is the most varied of the three groupings. It includes large and small firms, Canadian and foreign-owned firms, and end-of-pipe and process-integrated firms. Despite this variation however, it is still distinct from the other groupings as it contains more large firms and more process-integrated manufacturers. Consequently, this group is predominantly made up of large process-integrated firms, who are either Canadian or foreign-owned. On average they commit 6% of their sales towards R&D, and like group one, firms vary individually in their allocation from 1 - 10%. Generally, the firms in this group do not place great importance in the use of private or government sources of scientific and technical expertise. They place greater importance instead in government programmes for financial support for technology development. In addition, they view universities as important sources of scientific expertise.

Viewed with the results reported in Chapter 5, the results presented here indicate that the water and wastewater technology firms operate within a collaborative innovation environment. In Chapter 5, the basic parameters of the environmental-innovation model were established, concluding that a significant feature of the model was the strong linkages that exist between the suppliers of water and wastewater technology and their customers. This chapter builds on this initial conclusion by concluding that the WWT firms collaborate at some level with their customers in the development of their technology. This collaboration varies from minor adaptive technological changes to the co-development of particular compliance technologies. Regardless of the level of collaboration, further empirical support is provided for the environmental-innovation model.

Chapter 7: Summary and Conclusions

7.0 Introduction

In this dissertation I have examined the relationship between environmental regulation and innovation in the environmental technology industry. In particular, this enquiry explores the linkage between water pollution regulation and the development of water and wastewater technology, in the Province of Ontario. Although previous attempts have been made to examine the environmental regulation-innovation linkage, the spatial context in which the relationship occurs has been notably absent. In addition, these previous attempts have also failed to consider the organization of the innovation process at the level of the firm. This is extraordinary given that environmental regulation research and innovation research have evolved concurrently. This thesis responds to this shortfall by combining innovation theory with that of environmental regulation to develop a model of the environmental regulation-innovation relationship. This relationship is explored through the innovation process in Ontario's water and wastewater technology sub-sector. The result of this enquiry is the specification of an environmental-innovation model, which details clearly the relationship between environmental regulation and technology development, and specifies the pathway through which this relationship is channeled.

This chapter begins by synthesising the key findings of this research enquiry. This outlines how the environment-innovation model is an advancement on previous attempts to model the environmental regulation-innovation relationship. In addition, it reviews the innovation process among Ontario's water and wastewater technology firms. The chapter concludes with a discussion of the policy implications of this research and suggestions for future research.

7.1 Synthesis of Research Findings

7.1.1 Modeling the Environmental Regulation-Innovation Relationship

Over the last few years, the Canadian environmental technology industry has been singled out for special attention under the strategic industrial development plans of both the Federal Government and the Government of Ontario. This emphasis has been justified on the grounds that environmental regulation can contribute to industrial development by creating new industries dedicated to the development of environmental technologies. As a result, the intention of both the Federal and Provincial governments has been to use Canada's environmental regulations to encourage the emergence of an industry dedicated to the supply of technologies that allow firms subject to the regulations to achieve compliance.

While theoretical support for this argument has been drawn from a number of quarters, the work of Porter (1990, 1991) and Ashford (1993, 1994) is notable. On one hand, Porter argues that a strict regulatory environment acts to stimulate the growth of a competitive environmental technology sector. The requirement for firms to be compliant with the regulations automatically creates a demand for environmental technology, that in order to clear the market, will be satisfied by environmental technology suppliers. Thus, the demand conditions through the driving force of regulations will allow the supply side to prosper.

Ashford, on the other hand, argues that environmental regulation is directly linked to the environmental technology supply industry. In Ashford's scenario, environmental regulations act to stimulate both the demand side and the supply side equally. However, while the firm subject to the regulation may react in a number of different ways, the environmental technology sector is modeled to simply supply end-of-pipe technology in an off-the-shelf-fashion.

Although this earlier research illustrates the possible nature of the environmental regulation-innovation relationship, it has a number of flaws. First, there is a lack of solid empirical testing of the perceived relationships. Much of the empirical support is drawn from a limited number of case studies, and anecdotal sources. Second, they fail to adequately consider the dynamic, complex nature of the innovation process. Neither incorporate innovation theory into their ideas, yet the outcome of innovation research is pertinent to the issue. Much recent innovation research has evolved concurrently with the work of Porter and Ashford. In particular, this research has demonstrated that innovation is a collaborative process involving a number of different actors but especially the technology manufacturers and their customers (von Hippel 1988, Rosenberg 1982, 1994, Rothwell 1990, Freeman and Soete 1997). This co-operative relationship has been shown to be an important factor in the success of many technology producers.

To address this theoretical and empirical shortfall, I have proposed an alternative model of the environmental regulation-innovation relationship. In the environmental-innovation model described in Chapter 3, environmental regulation is placed within a broader system of innovation. In particular, the model considers the process of innovation at the level of the firm, especially the nature of the relationship between the producers of technology and their customers.

Through an analysis of the innovation process among water and wastewater technology firms in Ontario, empirical support is provided for the environmental-innovation model. As demonstrated in Chapter 5, environmental regulation does indeed influence the development of water and wastewater technology. However, the path through which this influence is channeled does not conform to the originally held expectation. Initially, WWT firms were assumed to react directly to environmental regulation. Thus, regulation was perceived to be a strong stimulus for innovation. This would be consistent with the direct link from environmental regulation to the environmental technology firm, in the environmental-innovation model. While there is some evidence in Chapter 5 that this does occur, this direct link is not as strong as originally expected. Instead, the regulatory influence is channeled through the compliance needs of the regulated firms. The environmental technology customers, acting in compliance with environmental regulation, play a much stronger role as a stimulus for innovation.

Because the technology-based 'approvals process' is the dominant policy instrument used to control water pollution in Ontario, it was hypothesized that more end-of-pipe technology would be produced. This is consistent with Ashford's model (Porter doesn't recognise the existence of different technology types). However, as shown in Chapter 5, the assumption held by the environmental policy literature needs modification. The results indicate that although more end-of-pipe technology is produced generally, it is no more likely to be produced under the influence of environmental regulation than process-integrated technology. Instead, the environmental technology firms will produce a variety of technologies, in accordance with the compliance requirements of the regulated firms rather than as a direct response to the technical requirements of individual environmental regulations. Consequently, environmental regulations do not act directly as a means to select between alternative paths of technological development.

The environmental-innovation model is effective also in representing firms of different sizes, and ownership. These differences in firm structure are not considered in either Porter's or Ashford's models, where all firms are treated as being relatively homogenous. In the case of firm size, small firms were expected to concentrate on the development of the more standardized end-of-pipe technology. This reflects a contention in the innovation literature that variations in ability to produce technology reflect, in part, variations in firm size (Rothwell 1990, 1994, Britton 1990, Freeman and Soete 1997). In the case of WWT firms however, the complexity of technology produced does not vary according to the size of the firm. In addition, there is no variation among the WWT firms due to size, in response to either innovation stimuli (regulation-led, or customer-led). Consequently, the environmental-innovation model is inclusive of all firm sizes.

The model also includes the actions of domestic and foreign firms. Originally, foreign-owned firms were not expected to produce both types of technology, focusing instead on the production of end-of-pipe technology. However, this research shows that the production of each technology type does not vary according to the ownership of the firm producing it. In addition, this research also indicates that the customer-led and the regulation-led innovation stimuli affect both groups of firms. While there is no variation between domestic and foreign firms in their response to the customer-led innovation stimulus, more domestic technology is produced in direct response to environmental regulation.

Overall, what is significant about the environmental-innovation model is that it is able to incorporate both the strong customer-led linkage and the weaker direct regulation-led linkage. Consequently, this adds to previous approaches in our understanding the relationship. Unlike previous models, the regulatory stimulus may be channeled exclusively through the regulated or customer firm, or may be a direct linkage between regulation and the environmental technology firm. This has the advantage of allowing the model to hold true for all firms under different policy choices and different technologies.

7.1.2 Describing the Innovation Process.

Chapter 5 provided empirical support for the basic structure of the environmental-innovation model. There, the analysis demonstrated that the innovation process governing the development of water and wastewater technology does not function on its own without environmental regulation playing a key role. However, the role of environmental regulation as an innovation stimulus is channeled through the regulated firms. The environmental technology firms will innovate in response to the regulatory needs of their customers, rather than reacting directly to the regulations themselves. As this customer-supplier relationship was shown to be fundamental to the operation of the environmental-innovation model, the main objective of Chapter 6 was to establish how this relationship was organized.

In summarizing the relationship between the water and wastewater technology firms and their customers, the analysis in Chapter 6 indicates that it is built around the production of customized technologies, that are produced on a 'one-at-a-time' basis. This is indicative of a fairly intensive relationship between the firms. The research also indicates that this intensive relationship shows no variation between firms on the basis of firm size, ownership, nor with the type of technology the firms are producing. Therefore, initially held hypotheses regarding weaker customer-supplier relationships among small firms, foreign-owned firms, and producers of end-of-pipe technology have been shown to be false. A number of conclusions can be drawn from this. First, small firms are as innovative as large firms and as a result have been able to overcome size-related obstacles to technology development. Second, foreign-owned firms are not limited to supplying technology in an arm's-length fashion, rather they establish cooperative linkages with local technology users resulting in the customization of their technology to suit local conditions. This customization is driven by regulatory differences between Ontario and the US.

Last, the fact that producers of end-of-pipe technology enjoy similarly interactive relationships with their customers as process-integrated technology indicates that the technology is not as standardized as originally thought. In fact, many of these technologies require significant redesign and engineering before they are installed. What this suggests is that Ashford is incorrect in assuming technology-based standards will result in the arm's length supply of this technology. The decision to use a particular technology is a function of the interactive nature of the relationship between the customer and supplier rather than a result of a particular type of regulation.

The results, reported in Chapter 6, also demonstrate that the collaboration between the customer and supplier is continuous, not ending with the installation of the technology. This, combined with the fact that the WWT firms focus their innovation efforts on incremental changes in their technology rather than the introduction of new technologies, verifies the depiction of the environmental-innovation model as representing a dynamic and iterative innovation process.

The close relationship between the WWT firms and their customers was found to be a result of the specialized nature of the water wastewater technology. The technology must achieve two points of compliance: it must fit with the customer's existing production process, and it must also fit with the regulations. Consequently both sets of firms possess knowledge which is complementary. While the WWT firms have the knowledge regarding the capability of their particular technology, the customer holds the knowledge regarding their production process. Consequently, this knowledge is complementary and can be traded, resulting in a close, interactive relationship between the two actors in the innovation process. When the analysis reported in Chapter 6 is combined with that of Chapter 5, a picture of the innovation process among water and wastewater technology firms emerges. Collectively, they are performing applied near-market R&D (Rustaert 1994, Narula 1999). The firms are working within their existing knowledge base where technological spillovers are low, and technological uncertainty and financial risk are reduced. This applied R&D, which is driven by the customer's compliance requirements, results in incremental changes in water and wastewater technology. The firm that is subject to environmental regulation has a number of choices. They can buy technology off-the shelf, they can develop their own technology internally, they can negotiate and sign a customized technology contract with an environmental technology firm, or they can co-develop a new technology with an environmental technology firm.

If the customer is in a high-pollution industry and compliance requires significant changes then it is unlikely it will buy technology off-the-shelf. The reason is that very few WWT firms are engaging in speculative technology development where a market for the technology is expected to exist at the end of the innovation cycle. It is unlikely they will develop their own compliance technology internally given the specialized nature of environmental technology. Therefore, they will most likely be forced to either co-develop a new technology or at the very least require substantial changes to be made to existing technology.

If customers do not need to advance their technology requirements because, as in the case of Ontario, the regulations are changed infrequently, then the WWT firms will re-customize existing technology to meet user needs. They will not create new technology because there is no incentive derived from the regulatory side due to regulatory stability. Therefore, the regulations do not trigger high levels of innovation. Instead they will induce customization to meet incremental changes in the customer's requirements.

7.2 Implications of the Research for Policy

While this research addresses explicitly the process of innovation in the Water and Wastewater technology sub-sector, a number of broader inferences can also be drawn. In particular, these can be interpreted within the realms of both industrial and environmental policy.

When the results of this research are placed alongside the statements published by various government departments, NGO's, and some consulting firms there is a clear difference. On the one hand, these other sources claim the existence of an extremely successful environmental technology sector, employing thousands of workers, and expected to achieve substantial growth in the future. On the other, this research shows that it is much smaller, and is organizationally more complex, than is claimed. In fact, in industrial statistics provided by StatCan, it is almost impossible to locate a dedicated environmental technology producing industry in a conventional sense. In particular, the environmental technology industry is very small in size, which hinders its ability to compete successfully against its foreign counterpart, it lacks a strong domestic market, and it is highly fragmented. Overall, therefore, it possesses many of the structural weaknesses that afflict Canadian industry in general.

On a more positive note, however, looking at individual firms or sub-sectors of the industry, the results are more encouraging. Using the Water and Wastewater Technology sub-sector as a case study, my research indicates that, although it is much smaller than is claimed, individual firms have been successful. The sector is dominated by small firms; the majority of firms are Canadian-owned indicating a large domestic presence in the industry; and the participant firms are quite innovative, involving the improvement of existing technology, new product development, and product customization. The firms are also able to exploit niche markets for their technologies, which are organized in terms of the technological approach used to prevent water pollution.

Porter argues that the environmental regulations will trigger innovation, thus acting as a catalyst for new industrial development. Because Canada is a 'regulatory follower', the environmental technology industry would be expected to be weak, relative to that in other jurisdictions internationally. In addition, because the dominant regulatory approach is the technology-based 'approval's process', much of the technology supplied would be expected to be the more standardized end-of-pipe technology. While environmental technology, as an industry, is smaller than is claimed by government and consulting firms, below the surface of this general industry view is a relatively successful Water and Wastewater technology sub-sector. This sub-sector is thriving in the face of weak water pollution legislation relative to that applied internationally, and is supplying technology across the spectrum of technology types.

Given this, a significant factor in the success of this sub-sector is the ability of firms to establish a close relationship with their customers (firms subject to environmental regulation). This is not an arm's length supplier relationship. Instead, it is a collaborative relationship that occurs regardless of the technology the firms are developing. In other words, the relationship is as strong for those firms developing the more traditional end-of-pipe technology, as it is for the developers of leading edge process-integrated technology. These inter-firm co-operative relationships occur not only with domestic users of the technology, but also with users located outside of Canada too.

Therefore, in trying to better understand the nature of the environmental technology industry, we in fact, end up with two contrasting pictures. On the one hand we have a general environmental technology industry which suffers from the same structural weaknesses as many other Canadian industries. On the other, once we scratch below the surface of this general view, we have a number of successful firms in a relatively successful sub-sector. It is possible that more firms could be successful if the policy environment were modified.

Stiffer environmental regulations might promote industrial development, but this argument ignores the organization of the innovation process that exists within a region. Environmental regulations are an important component of this overall system, however they are not the only part. Therefore they can be viewed as a necessary, but not a sufficient condition for the success of the environmental technology industry.

Although the thesis addresses the water and wastewater technology sector, the model specified can be applied to other sub-sectors of the environmental technology industry. As a result, it holds more generic applicability. As indicated in Chapter 1, the other dominant sectors of the Canadian environmental technology industry are air and waste management. In the case of air pollution regulations, the approach adopted by both the federal and provincial government mirrors that of water pollution regulations. At the federal level, air quality is protected under the Canadian Environmental Protection Act, through a series of regulations namely: National Air Quality Objectives; National Emission Guidelines; and National Emission Standards. Provincially, the Ontario Environmental Protection Act sets out a series of guidelines under the Ambient Air Quality Criteria and Regulation 346 (Estrin and Swaigen 1993). In similar fashion to water quality, the responsibility for the protection of air quality is left largely with the provinces. Moreover, this occurs through the 'Approvals' process. Unlike water pollution however, there is no 'air' equivalent of the MISA programme. With respect to waste management, responsibility is placed solely in the hands of the provinces. In Ontario, the principal regulatory instruments are the Environmental Protection Act (Part V) and Regulation 347 (Estrin and Swaigen 1993). Similar to water and air regulations, waste management is enforced through the 'Approvals' process.

Because the 'Approvals' process is common to water, air and waste management regulations, it is plausible to infer that the environmental-innovation model will have broader applicability outside of the water and wastewater technology sub-sector. In addition, because this research has shown that technology type does not vary according to the type of regulation in place, both end-of-pipe technology and process-integrated technology would be developed. Therefore the environmental-innovation model can be applied to the air and waste management sub-sectors, too.

The model may also be applicable to other jurisdictions within Canada and internationally, too. Across Canada, the approaches adopted by various provincial and territorial governments to controlling water pollution are similar to those in effect in Ontario.

While slight variations exist to take account of regionally specific water quality goals, all have adopted a permit system in similar fashion to Ontario's 'Approvals' process (MacDonald 1991). However, Ontario is the only province to adopt a programme targeting direct dischargers with standards based on a BAT format (MISA). Due to the similarity in regulatory approach, it is reasonable to assume that the environmental-innovation model would generate similar relationships as those modeled for Ontario.

As discussed in Chapter 2, water pollution regulations are applied in similar fashion internationally. In Germany, the US, and Sweden the favoured approach to preserving water quality is enforced through standards which incorporate a technological benchmark. But, because this research indicates that the type of technology developed is more a function of the relationship between the environmental technology firm and their customer, I would expect that the environmental-innovation model could be applied internationally. While customer-supplier relations with respect to innovation, are perceived to be weak for many industrial sectors in Canada (Hayter 1996, Gertler and Wolfe 1998), research suggests that the same cannot be said for the US, Sweden and Germany. In these three cases, research indicates that in many sectors, relations between customers and suppliers of technology are strong.[1]

Because customer-supplier relations are strong, with respect to innovation in these other international jurisdictions, it is entirely likely that they would also be strong with respect to the development of environmental technology. While no comprehensive studies exist on the organization of the environmental technology industry in these other countries, Porter (1990) and Solvell, Zander, and Porter (1992) provide anecdotal evidence from

[1] See for example, Cooke and Morgan (1998), Heidenreich and Krauss (1998), Heinze (1998), Scott

Sweden of co-operation between environmental technology firms and the Swedish mining and pulp and paper industries. Similarly, Grabher (1991), and Heinze et al (1998), have noted the emergence of an environmental technology industry in Germany out of the restructured iron and steel industry. In their work the innovation links between the environmental technology firms and the iron and steel firms are perceived to be strong suggesting initially that the environmental-innovation model could be applied.

Overall, this research demonstrates the need to place the innovation process squarely within an environmental-policy impact model. Through empirical analysis, a revised model of the environmental regulation-innovation relationship is advanced that has general applicability. While the model can be applied to different sub-sectors and jurisdictions, the most appropriate scale to conduct this analysis is at the level of the region. As noted in Chapter 4, it is inherently difficult to conduct research of this type treating all industry sub-sectors and regulatory jurisdictions collectively. Finally, this research demonstrates that the relationship between environmental regulation and technology development can only be understood with reference to the innovation process that underpins the actions of the technology producers.

7.3 Discussion of the Research Methodology

This enquiry can not be concluded without acknowledging some of the weaknesses that afflict survey-based research of this type. To gather data on the innovation strategies of the WWT firms, the principal survey instrument was a mail-out survey, supported by key

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(1998) Edquist and Lundvall (1993), de Vet and Scott (1992).

informant interviews. This was fraught with difficulty from the outset. Considerable time and effort was expended in identifying the population of WWT firms. The main difficulty was the lack of a comprehensive listing of these firms due to the fact that it is not a formally identified industrial sector under SIC classification codes. Consequently, listings of these firms are not published in traditional industrial directories that use this form of classification (for example Scott's Industrial Directory or Dun and Bradstreet).

Although all identified WWT firms were sent a survey, and the response rate was typical of many industrial surveys, the sample size was small. This restricted the range of analysis that could be performed on the data. Reliance had to be placed in many cases, on simple chi-square tests of association between variables. The intention, at the beginning of this research was to use multivariate probability techniques, for example logit models, or logistic regression. However, due to the small sample size this was not possible. It is difficult to determine how the number of surveys returned could have been improved given the usual pre-send methods were followed (for example, contacting the respondent prior to sending, enclosing a stamped return envelope). It is possible that the questionnaire could be redesigned making it simpler to fill out. However, there is a trade off between designing a simple questionnaire and one that will generate data of the type necessary for this type of research. Apart from questionnaire re-design, another method of improving the response rate would be to ensure the questionnaire is not administered during the months of July and August. Many of the firms had to be contacted several times prior to receiving the questionnaire as the respondent was away on vacation.

Although, the sample size was small, limiting the range of analytical possibilities, the data received can still be considered representative of the WWT sub-sector as a whole.

Consequently, the approach to the enquiry was appropriate, especially given the lack of depth characterizing existing studies of the industry in Canada.

7.4 Direction for Future Research

This research enquiry addresses the relationship between environmental regulation and technological innovation in the environmental technology industry. Using innovation in Ontario's water and wastewater technology sub-sector in response to water pollution regulations, an environmental-innovation model is advanced. In order to test the robustness of this model and thus refine its construction, it is necessary to explore the environmental regulation-innovation relationship in other sectors of the environmental technology industry in Ontario, especially air and waste management. In addition to water and wastewater, air and waste management are the other dominant sectors of the Canadian environmental technology industry. Although this current research speculates that the model is applicable to these other sectors, it must be tested empirically.

The applicability of the model must also be tested under different jurisdictions. Nationally, this will involve the environmental technology industries in Quebec and Western Canada, which in addition to Ontario, are the largest concentrations of industrial activity in Canada. Britton (1996) notes that a clustering of Environmental-Energy industrial activity in Western Canada has occurred in response to resource and mineral extraction activity there. The analysis should also be extended to include an international comparison, to evaluate how the Canadian environmental regulation-innovation linkage compares against that of the US and Europe particularly the case of Sweden. Porter (1990) cites the industry in Sweden to support his model, however, he provides no empirical or case study evidence to support his argument. By testing the environmental-innovation model in other provincial, and international settings a better understanding of the regulation-innovation linkage should be possible.

This research enquiry focused on the supply-side, examining the actions of the water and wastewater technology firms. A small number of key informant interviews were carried out with customer firms to attempt to further understand the customer-supplier relationship. In order to ground fully the environmental-innovation model, further research is necessary on the demand-side. This is especially the case as environmental regulations are not the only driver of technology acquisition (other drivers include cost savings, energy and materials savings, and supply chain influences) (KPMG 1995). In addition, the decision to adopt environmental technology may be influenced by the organizational strategies of the regulated firms (Atlas and Florida 1997, Florida, Atlas and Cline 1999). Firms undergoing a process of restructuring for example, are more likely to adopt compliance technology in anticipation of regulatory change (Dupuy 1997).

The relationship between the firms developing environmental technologies and their customers will be examined further, especially given that the supply and demand for environmental technology is a composite of relations between foreign and domestic firms. This will permit an investigation of the regional specificity of the process of innovation, in the face of the continued globalization of economic activity. By advancing our understanding of how regional institutions affect technological change, the research will contribute to the current interest within economic geography in understanding the importance to economic development of regional as opposed to national and international innovation systems.

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Appendix 1

Water and Wastewater Technologies

Table 1a: Water and Wastewater Technologies, by Technology Type

Process-Integrated	
Chlorine Dioxide Generators	Acid Purification System
Reverse Osmosis Membranes	UltraViolet Purification and Disinfection System
Biosolid Extraction and Transportation System	Chlorination/Dechlorination System
Deionization System	
Ultrafiltration System	
Closed-loop Chemical Recovery System	

End-of-Pipe	
Sewage Pumping System	Liquid/Solid Separators (Pulping)
Suspended Solid Monitors	BioTreatment Aeration System
Oil/Water Separators (Laser and Fibre Optic)	Anaerobic Digesters
Sludge Thickening/Dewatering System	Carbon Vibroscreens
Activate Carbon Filters	Granular Media Filtration
Electrostatic Filters	Chemical Precipitation
Wastewater Clarifiers	Steam Strippers
	Chemical Oxidation/Reduction

Appendix 2

Industrial Sectors covered under MISA

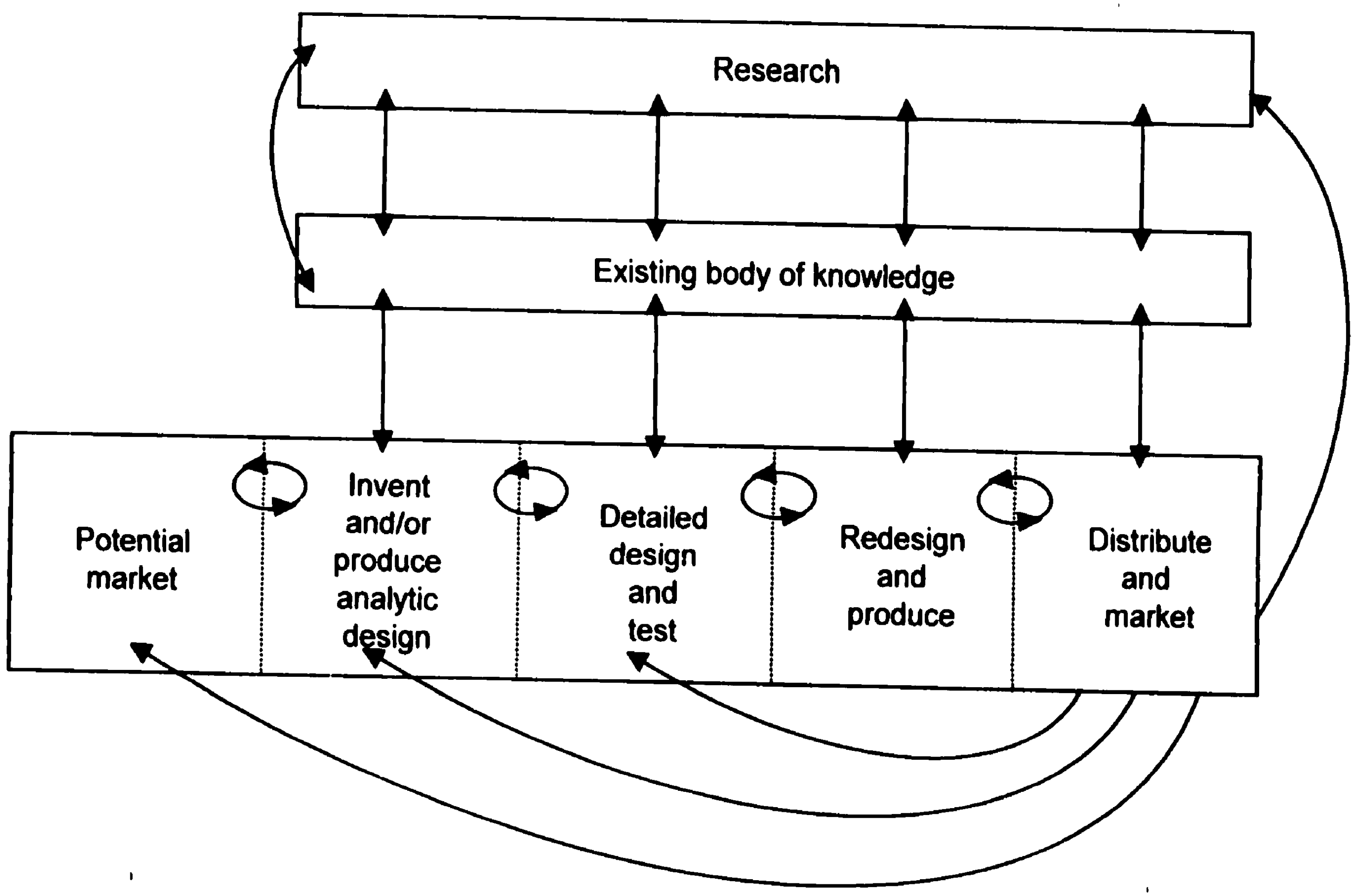
Table 2a: Industrial Sectors Covered under the MISA Programme

Petroleum Refining
Organic Chemicals
Inorganic Chemicals
Pulp and Paper
Iron and Steel
Metal Mining and Refining
Metal Casings
Industrial Minerals and Manufacturing
Electric Power Generation

Appendix 3

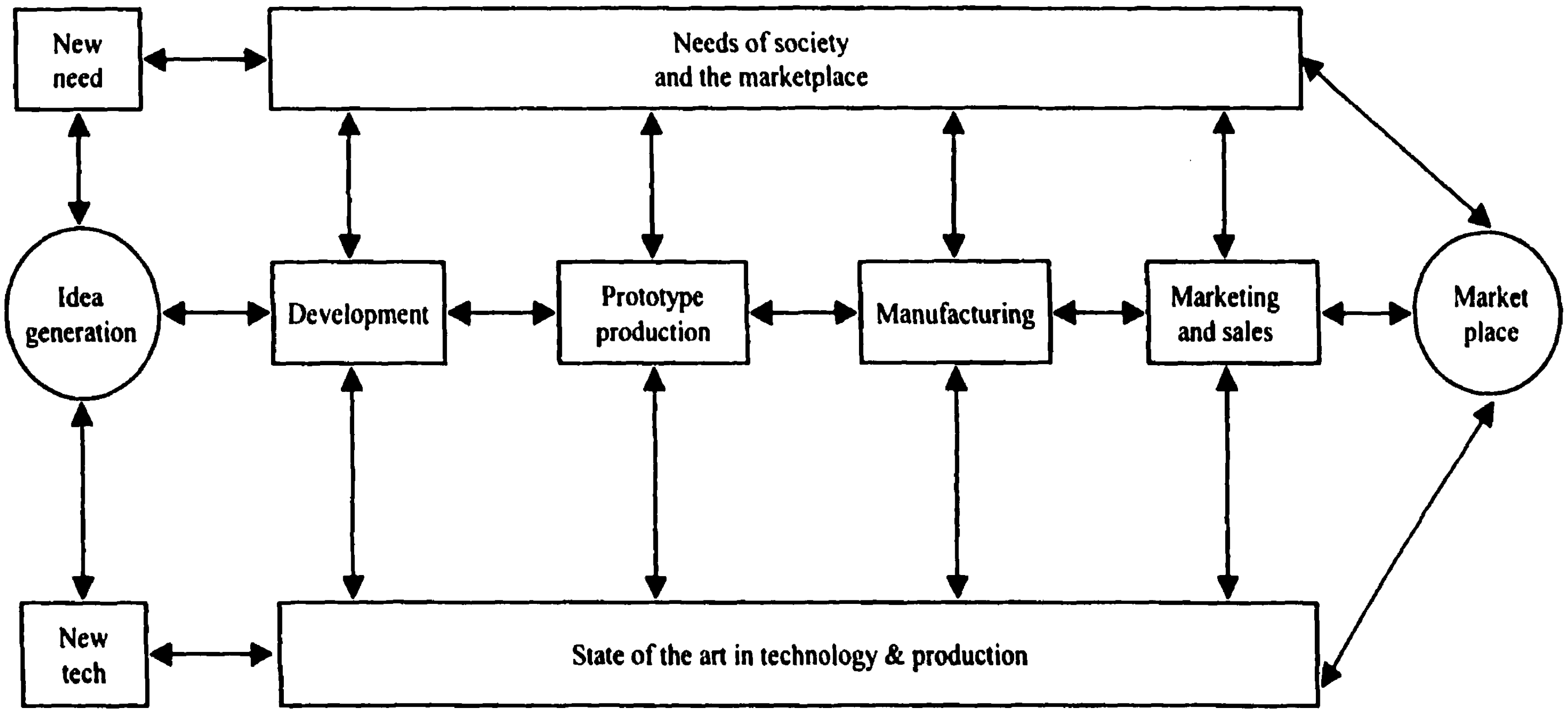
Interactive Innovation Models

Appendix 3A: Chain-Linked Model of Innovation



Source: Kline and Rosenberg 1986

Appendix 3b: Coupling Model of Innovation



Source: Rothwell 1992, Rothwell and Zegveld 1985

Appendix 4

Survey and Interview Questionnaires, Map

Exploring Canada's Strengths in Environmental Technology

Dear

The Canadian Environmental Technology Industry occupies an important position within the industrial development of Canada, yet few studies have examined the link between this industry and Canadian environmental policy.

In my Ph.D. research, I am conducting a survey of Ontario suppliers of Water Pollution Control and Prevention Technology.

I would greatly appreciate your participation in this survey: The success of this project depends on receiving information from members of this industry. The enclosed questionnaire is designed so that I can assemble essential information on the process of technology development in this industry. In particular, I am interested in understanding how the impetus for technological development is generated, and whether current environmental policies make a decisive contribution.

All answers will be kept **strictly confidential**. The responses will not be reported individually but will be aggregated and used as survey responses. This research is being conducted under the ethical protocols of the University of Toronto. You may contact my supervisor to verify my status: Prof. John Britton - Fax 416-978-1649; Phone 416-978-2384; e-mail John.Britton@utoronto.ca

The project is supported by a fellowship from the Social Sciences and Humanities Research Council of Canada.

The results of the survey will be summarized in a short report. If you would like a copy of this report, please indicate so at the end of the questionnaire.

If you have any questions or require further clarification please do not hesitate to contact me at the above address or telephone 416-978-4812, 416-xxx-xxxx (Home), or e-mail: dupuy@geog.utoronto.ca.

I really appreciate your co-operation with this project and thank you for your time.

Yours sincerely

Damian A. Dupuy
Ph.D. Candidate

Exploring Canada's Strengths in Environmental Technology

Please complete the following. Be assured that ANONYMITY and CONFIDENTIALITY will be maintained with regard to ALL information received in this questionnaire. Feel free to use the back of this questionnaire if space is limited.

Your Name:______________________ Title:__________________

Company Name:__________________ Telephone Number:(   )__________

1. Approximately what % of your firm's revenues are due to each of the following activities:

   ______Manufacturing (own technology or technology under license)

   ______Distribution of products/systems manufactured elsewhere

   ______Provision of scientific and/or engineering services

2. Please allocate your output (% of the value) to the following product groups:

   ______% Water Pollution Control

   ______% Air Pollution Control

   ______% Waste Management

   ______% Other (please specify__________________________________

3. Please provide a brief description of the three *most important (by sales value)* **Water Pollution Control/Prevention** products/systems you manufacture. Please indicate the technology involved and the generic name of the product.

Product/System #1____

____

Product/System #2____

____

Product/System #3____

____

4. Please indicate which of the following classifications of environmental technology best describes each of the products/systems listed in question 3. Please check ✓ only one classification for each product/system.

	End-of-Pipe Technology	Process-integrated Technology	Other, specify
Product/System #1			
Product/System #2			
Product/System #3			

5. Please **RANK in order of importance** the following motivations for the development of each of the products/systems listed in question 3. (The most important would be ranked 1, the next most important would be ranked 2 and so on.)

	Environmental Regulation	Response to particular customer's needs	Identified an Environmental Need	Other, specify
Product/System #1				
Product/System #2				
Product/System #3				

6. For each product/system, indicate the specific regulatory influence (e.g. MISA, Ontario Water Resources Act, Fisheries Act) which stimulated its development.

	Environmental Regulation
Product/System #1	
Product/System #2	
Product/System #3	

7. Please **RANK** the following sources of information on the technical requirements of the Environmental Regulations listed above, **in the order you received them**. (The earliest source would be ranked 1, the next earliest would be ranked 2 and so on.)

	Government	Customer	Firm in the same industry	Your Industry Association	Other, specify
Product/System #1					
Product/System #2					
Product/System #3					

8. Do Ontario's environmental regulations strongly influence your product development process?

☐ Yes ☐ No

If Yes, Please explain

____

____

____

____

____

9. Where were the products/systems identified in question 3 **originally developed**? (check ✓ one for each product/system).

	In-house	Under license	Parent firm	Customer firm	Other supplier	Other, specify
Product/System #1						
Product/System #2						
Product/System #3						

10. If developed with a customer please indicate their **location and industry**. Please include the city, province/state, and country as applicable.

	Location	Industry
Product/System #1		
Product/System #2		
Product/System #3		

11. At what stage of the product development process did you receive input from a customer? Please check ✓ one for each product/system listed in question 3.

	Basic Research	Design	Engineering	Testing	Marketing	Other, specify
Product/System #1						
Product/System #2						
Product/System #3						

12. Overall, how important has your relationship with a customer been to the development of your technologies? Please check ✓ one for each product/system listed in question 3.

	Not important at all	Not particularly important	Important	Very important	Extremely important
Product/System #1					
Product/System #2					
Product/System #3					

13. Have you modified your existing technologies by introducing new design features? (check ✓ one).

☐ Yes, new design features introduce

☐ No, original design in production (continue to question 14)

If Yes, please answer (a)

(a). What were the primary reasons for introducing the new design features, and who suggested them (e.g. supplier, customer etc.)? (Please indicate which product/system number you are referring to.)

____

____

____

____

14. What proportion of your R&D (including design and engineering) expenditures is accounted for by the following?

Updating/improving existing products/systems _______%

Introduction of entirely new products/systems _______%

Modification of products for particular customers _______%

15. Approximately what proportion of your gross annual sales went to R&D (including design and engineering) activities in the following years?.

1987__% 1989__% 1991__% 1993__% 1995__%

16. Did your firm engage in any co-operative activities with other firms (e.g. customers and suppliers) in the development of the products/systems listed above? (check ✓ one)

☐ Yes ☐ No (continue to question 17)

If Yes, please specify which product/system and describe the relationship.

____

____

____

____

____

17. To what extent do your customers depend on your firm for technical assistance to integrate your products/systems into their existing production system? Please circle one point.

Do Not Depend On Us At All 1 2 3 4 5 *Depend On Us Entirely*

18. Approximately what % of your production, by value, falls into the following categories?.

___ Products made one-at-a-time to customer's orders
___ Products made in short batch runs
___ Products made in long production runs
___ Other (please specify)

19. Please describe the origins of your firm (check ✓ all that apply).

☐ Spin-off from research organization or university
☐ Spin-off from larger manufacturing firm
☐ Result of a merger with, or acquisition of, another firm
☐ Commercialization of an original technical invention or idea
☐ Based on a technology purchased or licensed at arm's length
☐ Other (please specify)

20. Approximately how many of the following types of workers do you employ?

____ Management
____ Engineers/Scientific
____ Skilled shop floor workers
____ Unskilled shop floor workers
____ Office/Clerical
____ Warehouse and shipping
____ Other (please specify)__________

21. Is your firm part of a multi-plant company? ☐ Yes ☐ No

22. Is your firm ☐ Canadian-owned ______% ☐ Foreign-owned ________%

If **foreign-owned**, what is the location of your parent company's head office? ____________________

____

____

23. Do you manufacture in countries outside of Canada?

☐ Yes ☐ No (continue to question 24)

IF YES Please answer (a) and (b)

(a) Please list the countries ____

(b). Do you modify the products/systems to suit the requirements of the environmental regulations in other countries? Please circle one only.

No modification 1 2 3 4 5 *Considerable modification*

24. Please **RANK in order of importance**, the following purchasers of your technology, for each geographical category that applies. (The most important purchaser would be ranked 1, the next most important would be ranked 2 and so on.)

	National or Provincial government	Municipal government	Resource industries	Manufacturing industries	Other, specify
In Ontario					
In rest of Canada					
Foreign					

25. Do you modify the products/systems you **export** to suit the requirements of the environmental regulations in other countries? Please circle one only.

No modification 1 2 3 4 5 *Considerable modification*

26. Please allocate the % (by sales value) of your sales to the following categories:

_____% sold directly to end user _____% sold via an intermediary (wholesaler/re-distributor)

27. Overall, who are your biggest (by sales volume) customers in Ontario? Please state their name.

____

____

____

28. Please indicate how important the following sources of outside technical/professional support have been to your technological strategy overall. Please circle one number for each source.

Source of Support	*Not Important* 1	2	3	4	*Critically important* 5
Private industrial design services	1	2	3	4	5
Private Research and Development services	1	2	3	4	5
Private Engineering services	1	2	3	4	5
Ontario Centre for Environmental Technology Advancement	1	2	3	4	5
Government Research programs (e.g. ETP, IRAP)	1	2	3	4	5
Government Research Services (e.g. NRC)	1	2	3	4	5
Testing laboratories	1	2	3	-4	5
Universities	1	2	3	4	5
Market research	1	2	3	4	5
Customers	1	2	3	4	5
Suppliers	1	2	3	4	5
Distributors	1	2	3	4	5
Other, please specify	1	2	3	4	5

The following questions will be helpful to me in interpreting your responses. Please be assured that all information is STRICTLY CONFIDENTIAL.

29. Approximately what were your gross annual sales for the following years ?

1987 $____ 1989 $____ 1991 $____ 1993 $ ____ 1995 $

30. Approximately what proportion of your gross annual sales were for export ?

1987 ___% 1989 ___% 1991 ___% 1993 ___% 1995 ___%

31. Approximately what proportion of your gross annual sales were invested in machinery and equipment ?

1987 ___% 1989 ___% 1991 ___% 1993___% 1995 ___%

32. In what year was this plant established?

33. Approximately how many workers were employed at this plant during the following years ?

1987____ 1989____ 1991____ 1993____ 1995

Would you like to receive a summary of the study's findings?

☐ Yes ☐ No

Do you have any other comments on the issues raised in this questionnaire that you feel may be helpful to this study?

____

____

____

____

____

Thank you for your time and co-operation!

INTERVIEW GUIDE - Supplier Firms

DATE:_________________ **FORMAT**_____________

NAME:____

POSITION:____

ORGANIZATION:______________________________________

COMPANY INFORMATION

Employees ____

Ownership (%) ____

Do you manufacture in countries outside of Canada?

☐ Yes ☐ No

1. What proportion of your sales is exported

QUESTIONS REGARDING REGULATION

2. What regulations in particular influenced you? (MISA, OWRA, Fisheries Act).

3. Overall, would you say that Ontario's regulations are a strong influence?.

QUESTIONS REGARDING THE INNOVATION STRATEGY

4. At what stage of the product development process did you receive input from a customer?

5. Overall, how important has your relationship with your customers been to the development of your technologies?

6. What were some of the reasons for adopting this approach as part of your innovation strategy?

7. Are the technological agreements you have with the firms formal or informal. In other words do you solidify the relationship with a formal contract, MOU, etc. Are there privacy agreements signed to prevent the leakage of technology?

8. How important is proximity the firms in the design of these technologies. Could the same result occur in a non face to face environment.

9. Is leadership or co-ordination a joint effort, or does one or other party assume lead.

10. Did your firm engage in any other co-operative activities with other firms (e.g. strategic alliances, joint ventures) in the development of the technologies? Please explain.

11. To what extent do your customers depend on your firm for technical assistance to integrate your technology into their existing production system?.

12. Do you use any external services as part of your innovation strategy, and how important are they. What were the reasons for using these external services?

13. Do you sell the technology to other firms, outside of those you work directly with.

14. Are you solely a manufacturer, or do you provide scientific and engineering services too? What

15. How are most of the technologies funded, in terms of a breakdown in percentages between all the co-operative parties?

16. Overall what barriers to competitiveness do environmental technology firms in Ontario face?

INTERVIEW GUIDE - Customer Firms

DATE:____________	**FORMAT**____________
NAME:____________________________	
POSITION:____________________________	
ORGANISATION:____________________________	

Questions concerning use of Environmental Technology

1. How would you categorise the technologies you employ to reduce water pollution in terms of pollution control or pollution prevention.

2. What were the principal motivations from adopting the particular technologies you use to control/prevent water pollution. Were environmental regulations a direct influence. or were the decisions made for a combination of reasons e.g. potential cost savings, materials savings, improved competitive position etc..

3. If regulations, what ones in particular ? (MISA, OWRA, Fisheries Act).

4. Overall, would you say that Ontario's regulations have strong or weak influence?.

5. Have voluntary initiatives, like ISO 14000 had any influence on your decision to adopt compliance technology

6. From were did you receive technical information on the environmental technologies you have implemented. Was it from government, the firms, or from your own research.

7. Did you purchase these technologies "off-shelf", were they co-developed with another firm, or were they developed (and manufactured) in house.

8. If co-developed, was it with a Canadian Supplier or a foreign supplier? Why?

9. At what stage of the innovation process did you collaborate with your supplier?

   - ☐ Basic Research
   - ☐ Design/Engineering
   - ☐ Testing

   Other _______

10. Was the relationship a 'once-off' situation or is it a continuous process, with frequent modifications etc.

11. How important is proximity to your supplier in the adoption/co-development your compliance technology?. Could the same result occur in a non face to face environment?.

12. Are the technological agreements you have with the supplier firms formal or informal. In other words do you solidify the relationship with a formal contract, MOU, etc.

INTERVIEW GUIDE - Government

DATE:____________________	**FORMAT**__________
NAME:____	
POSITION:______________________________________	
ORGANISATION:__________________________________	

Questions concerning Environmental Regulation

1. Why is the standards or command and control approach the most common approach to environmental policy used by the MOEE.

2. Are the standards or limits developed with the view that they many directly or indirectly stimulate technological innovation in pollution control or prevention technology. Or, does technology factor into the decision at all.

3. Once the limits or standards are put in place, are they adjusted periodically for example, as more innovative technology comes along. In other words is there a process of ratcheting in place.

4. In a review process are there economic impact studies undertaken of the impact of particular regulations on the competitiveness of the various regulated industrial sectors.

5. What role will other approaches to regulation especially economic instruments and voluntary agreements play in encouraging industries to develop and implement new pollution control and prevention technologies, in the future.

6. How do Ontario's water pollution regulations compare with other jurisdictions both provincially and internationally.

7. How much overlap occurs between the MOEE and the Federal Environment Ministry

Table 4a: The Relationship between Respondents and Non-Respondents, by Establishment Size

Count (Row pct) (Col Pct)	**SME**	**Large**	Row Total
Respondents	**29** (80.6) (47.5)	**7** (19.4) (36.8)	**36** (45.0)
Non-Respondents	**32** (72.7) (52.5)	**12** (27.3) (63.2)	**44** (55.0)
Column Total	**61** (76.3)	**19** (23.8)	**80** (100)

Chi-Sq .(continuity correction) = .30748
DF = 1
p = .57923

Table 4b: The Relationship between Respondents and Non-Respondents, by Ownership

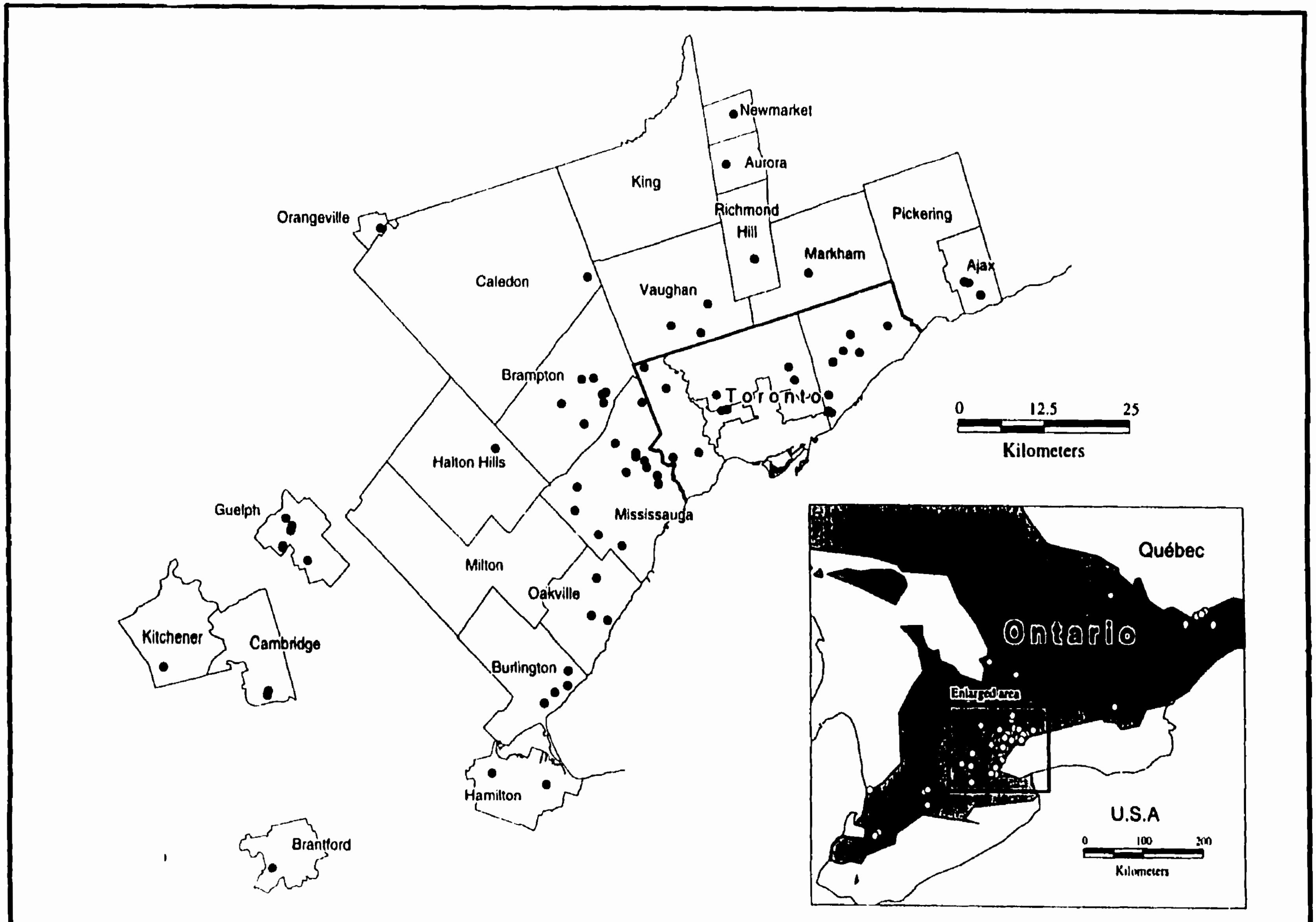
Count (Row pct) (Col Pct)	**Canadian**	**Foreign**	Row Total
Respondents	**27** (75.0) (43.5)	**9** (25.0) (50.0)	**36** (45.0)
Non-Respondents	**35** (79.5) (56.5)	**19** (24.1) (59.1)	**44** (55.0)
Column Total	**62** (77.5)	**18** (24.4)	**80** (100)

Chi-Sq . (continuity correction) = .04634
DF = 1
p = .62813

Table 4c: Distribution of Respondents, by Firm Size

TYPE	DEFINITION	FREQUENCY	PERCENTAGE
Small	Single Establishment <50 employees	19	52.8
Large	Multilocational, Single Establishment >50 employees	17	47.2

Figure 4a: Distribution of Water and Wastewater Technology Firms in Ontario



Sources: Industry Canada 1993, CEIA 1995, Canadian Environmental Directory 1995

Appendix 5

Statistical Tests in Support of Chapter 5

Table 5a: The Relationship between Technology Type and Regulation Type

Count (Row Pct) (Col. Pct)	**MISA**	**OWRA**	**Other**	Row Total
End-of-Pipe	**8** (30.8) (44.4)	**13** (50.0) (65.0)	**5** (19.2) (50.0)	**26** (54.2)
Process-integrated	**10** (45.5) (55.6)	**7** (31.8) (35.0)	**5** (22.7) (50.0)	**22** (45.8)
Column Total	**18** (37.5)	**20** (41.7)	**10** (20.8)	**48** (100)

Chi-Sq. = 1.70	DF = 2	p = .427

Table 5b: The Relationship between Firm Ownership and the Modification of Technology in Non-Domestic Markets.

Do you modify your technology to suit the requirements of environmental regulations in other countries?

Count (Row pct.) (Col. pct.)	**NO**	**YES**	Row Total
Canadian	**2** (18.2) (50.0)	**9** (81.8) (60.0)	**11** (57.9)
Foreign	**2** (25.0) (50.0)	**6** (75.0) (40.0)	**8** (42.1)
Colum Total	**4** (21.1)	**15** (78.9)	**19** (100)

Chi.-Sq. = .129	DF = 1	p (Fisher's) = .574

Table 5c: The Relationship between Firm Ownership and the Influence of a Direct Response to Customer Need

Count (Row pct) (Col. Pct)	**Canadian**	**Foreign**	Row Total
No Influence	**7** (63.6) (11.9)	**4** (36.4) (21.1)	**11** (14.1)
Influence	**52** (77.6) (88.1)	**15** (22.4) (78.9)	**67** (85.9)
Column Total	**59** (75.6)	**19** (24.4)	**78** (100)

Chi-Sq. .= 1.00	DF = 1	p (Fisher's) = .258

Table 5d: The Relationship between Firm Size and the Influence of a Direct Response to Environmental Regulation

Count (Row pct) (Col. Pct)	**Small**	**Large**	Row Total
No Influence	**9** (40.9) (21.4)	**13** (59.1) (36.1)	**22** (28.2)
Influence	**33** (58.9) (78.6)	**23** (41.1) (63.9)	**56** (71.8)
Column Total	**42** (53.8)	**36** (46.2)	**78** (100)

Chi-Sq. = 2.064	DF = 1	p (Fisher's)= .208

Table 5e: The Relationship between Firm Size and the Influence of a Direct Response to 'Customer Need'

Count (Row pct) (Col. Pct)	**Small**	**Large**	Row Total
No Influence	**3** (27.3) (7.1)	**8** (72.7) (22.2)	**11** (14.1)
Influence	**39** (58.2) (92.9)	**28** (41.8) (77.8)	**67** (85.9)
Column Total	**42** (53.8)	**36** (46.2)	**78** (100)

Chi-Sq. = 3.639	DF = 1	p (Fisher's) = .100

Appendix 6

Statistical Tests and Background Tables in Support of Chapter 6

Table 6a: Relationship between Ownership and R&D Intensity

Count (Row Pct.) (Col. Pct.)	**Canadian**	**Foreign**	**Row Total**
Low/Medium-Low	**17** (70.8) (63.0)	7 (29.2) (77.8)	**24** (66.7)
High/Medium-High	**10** (83.3) (37.0)	**2** (16.7) (22.2)	**12** (33.3)
Column Total	**27** (75.0)	**9** (25.0)	**36** (100.0)

Chi-Square = .667	DF = 1	P Fisher's) = .685

Table 6b: Importance of Customer Support by Firm Size[1]

Count (Row Pct.) (Col. Pct.)	**Small**	**Large**	Row Total
Not Important	**1** (50.0) (5.3)	**1** (50.0) (6.3)	**2** (5.7)
Moderately Important	**5** (50.0) (26.3)	**5** (50.0) (31.3)	**10** (28.6)
Very Important	**13** (56.5) (68.4)	**10** (43.5) (62.5)	**23** (65.7)
Column Total	**19** (54.3)	**16** (45.7)	**56** (100.0)

[1] The significance levels for Tables 6b, 6c, and 6d are p=.935, p=.636, and p=.423 respectively. However, in each of these chi-square tests, more than 20% of the cells had expected values of less than 5.

Table 6c: Importance of Customer Support by Firm Ownership

Count (Row Pct.) (Col. Pct.)	**Canadian**	**Foreign**	Row Total
Not important	**1** (50.0) (3.8)	**1** (50.0) (11.1)	**2** (5.7)
Moderately Important	**7** (70.0) (26.9)	**3** (30.0) (33.3)	**10** (28.6)
Very Important	**18** (78.3) (69.2)	**5** (21.7) (55.6)	**23** (65.7)
Column Total	**26** (74.3)	**9** (25.7)	**35** (100.0)

Table 6d: Importance of Customer Support by Technology Orientation

Count (Row Pct.) (Col. Pct.)	**End-of-Pipe**	**Process Integrated**	**Multi-Technology**	Row Total
Not Important		**2** (100.0) (15.4)		**2** (5.7)
Moderately Important	**5** (50.0) (29.4)	**3** (30.0) (23.1)	**2** (20.0) (40.0)	**10** (28.6)
Very Important	**12** (52.2) (70.6)	**8** (34.8) (61.5)	**3** (13.0) (60.0)	**23** (65.7)
Column Total	**17** (48.6)	**13** (37.1)	**5** (14.3)	**36** (100.0)

Table 6e: Mean Proportional Allocation of Production of WWT Firms, by Ownership (%)

PRODUCTION	CANADIAN	FOREIGN	ALL FIRMS
One-at-a-Time to customer's orders	53.7	40.6	50.6
Short Batch Runs	26.9	26.3	26.8
Long Production Runs	19.2	33.1	22.5
TOTAL	100.0	100.0	100.0

Source: Survey Data
(Note: Allocations between Canadian and Foreign Firms not significantly different; Mann Whitney test, $p=0.05$)

Table 6f: Government Programmes to Support the Development of Environmental Technology

PROGRAMME	PURPOSE
Environmental Technology Commercialization Program	Provides financial assistance for small firms to develop and commercialize new environmental technologies. The funding is provided for either preliminary studies or demonstration costs.
D-RECT Programme	Funds the demonstration of new environmental technologies that not only reduce pollution, but also provide energy savings.
Program of Energy Research and Development (PERD)	Supports energy related R&D
Industrial Research Assistance Program (IRAP)	Through the National Research Council (NRC), funding, technical information, and engineering expertise is provided to small and medium sized firms to offset the financial risk associated with technology development.
Environmental Innovation Program (EIP)	Provides funding for the establishment of partnerships between environmental technology firms, government departments, and universities.

Technology Transfer Program	Provides financial assistance in the development and transfer of environmental technology.
Research Partnerships Program	Through the Natural Sciences and Engineering Research Council of Canada (NSERC), funds the development of partnerships between environmental technology firms and universities.
Technology Partnerships Canada	Provides funding for the development of selected technologies that have significant social and economic benefits. Activities that qualify for funding include: technical feasibility studies; development of near market technology; and pre-production activities. This program tends to favour environmental process and systems technologies rather than products.
Applied Pollution Prevention Program, Ontario	Funds the development, refinement and commercialization of environmental products and processes.
Scientific Research and Experimental Development (SR&ED) Tax Credit	Allows a refundable tax credit on qualifying R&D expenditures made by firms.

Source: Various Industry Canada and Environment Canada publications, Environment Canada 1997

Table 6g: Sources of External Technical/Professional Support by Firm Size: Mean Scores[2]

SOURCE OF EXTERNAL SUPPORT	SMALL	LARGE	ENTIRE SAMPLE
Private Industrial Design Services	1.47	1.37	1.43
Private R&D Services	1.31	1.18	1.26
Private Engineering Services	2.15	1.62	1.91
Testing Laboratories	1.94	1.87	1.91
Government Research Programs	2.21	1.56	1.91
Government Research Services	2.0	1.31	1.69
Ontario Centre for Environmental Technology Advancement (OCETA)	1.26	1.18	1.23
Market Research Consultants	2.0	1.87	1.94
Distributors	2.26	1.37	1.88
Universities	1.94	2.37	2.14
Suppliers	3.05	2.18	2.60
Customers	3.73	3.56	3.65

Source: Survey Data

[2] The firms ranked the importance of each source of external support on a scale ranging from "1=not important" through to "5=critically important".

Table 6h: Sources of External Technical/Professional Support by Technology Type: Mean Scores[3]

SOURCE OF EXTERNAL SUPPORT	END-OF-PIPE	PROCESS INTEGRATED	MULTI-TECHNOLOGY	ENTIRE SAMPLE
Private Industrial Design Services	1.47	1.15	2.0	1.43
Private R&D Services	1.11	1.23	1.80	1.26
Private Engineering Services	2.23	1.30	2.6	1.91
Testing Laboratories	1.64	1.35	3.2	1.91
Government Research Programs	1.7	1.53	3.4	1.91
Government Research Services	1.47	1.38	3.2	1.69
Ontario Centre for Environmental Technology Advancement (OCETA)	1.11	1.23	1.6	1.23
Market Research Consultants	1.88	1.76	2.8	1.94
Distributors	2.17	1.23	2.4	1.88
Universities	1.76	2.38	2.8	2.14
Suppliers	3.11	2.0	2.4	2.60
Customers	3.94	3.46	3.2	3.65

Source: Survey Data

[3] The firms ranked the importance of each source of external support on a scale ranging from "1=not important" through to "5=critically important".

Table 6i: R&D Group A, selected structural characteristics

R&D INTENSITY GROUP	SIZE (n)	OWNERSHIP (n)	TECHNOLOGY TYPE (n)
A Low 1-5% n = 13	**Small** (6)	**Canadian** (6)	**End–of-Pipe** (4)
			Process Integrated (2)
			Multi-Technology (0)
	Large (7)	**Canadian** (3)	**End-of-Pipe** (1)
			Process Integrated (2)
			Multi-Technology (0)
		Foreign (4)	**End-of-Pipe** (3)
			Process Integrated (1)
			Multi-Technology (0)

Table 6j: R&D Group B, selected structural characteristics

R&D INTENSITY GROUP	SIZE (n)	OWNERSHIP (n)	TECHNOLOGY TYPE (n)
B Medium Low 6-9% n = 11	**Small** (4)	**Canadian** (4)	**End–of-Pipe** (3)
			Process Integrated (1)
			Multi-Technology (0)
	Large (7)	**Canadian** (4)	**End-of-Pipe** (1)
			Process Integrated (3)
			Multi-Technology (0)
		Foreign (3)	**End-of-Pipe** (0)
			Process Integrated (2)
			Multi-Technology (1)

Table 6k: R&D Group C, selected structural characteristics

R&D INTENSITY GROUP	SIZE (n)	OWNERSHIP (n)	TECHNOLOGY TYPE (n)
C Medium High 10-14% n = 8	**Small** (5)	**Canadian** (5)	**End-of-Pipe** (4)
			Process Integrated (0)
			Multi-Technology (1)
	Large (3)	**Canadian** (1)	**End-of-Pipe** (0)
			Process Integrated (1)
			Multi-Technology (0)
		Foreign (2)	**End-of-Pipe** (1)
			Process Integrated (1)
			Multi-Technology (0)

Table 6I R&D Group D, selected structural characteristics

R&D INTENSITY GROUP	SIZE (n)	OWNERSHIP (n)	TECHNOLOGY TYPE (n)
D High >15% n = 4	**Small** (4)	**Canadian** (4)	**End–of-Pipe** (1)
			Process Integrated (0)
			Multi-Technology (3)
	Large (0)	**Canadian** (0)	**End-of-Pipe** (0)
			Process Integrated (0)
			Multi-Technology (0)
		Foreign (0)	**End-of-Pipe** (0)
			Process Integrated (0)
			Multi-Technology (0)