Universitat Ramon Llull

DOCTORAL THESIS

Title	**THE TAKEOFF OF ENVIRONMENTAL TECHNOLOGIES: A HISTORICAL ANALYSIS OF TIMING AND AFFECTING FACTORS.**
Presented by	**GIULIA CALABRETTA**
Centre	ESADE – ESCUELA SUPERIOR DE ADMINISTRACIÓN Y DIRECCIÓN DE EMPRESAS.
Department	MARKETING, OPERATIONS AND FINANCE
Directed by	DR. JORDI MONTAÑA MATOSAS

Table of Content

Index of Figures

Index of Tables

Chapter One

Introduction

1.1 Motivation for the study

In the last decades the uncontrolled impact of industrial activities on the natural environment has created critical ecological concerns. The aggravation of phenomena like climate change, ozone depletion, overexploitation of natural resources, air pollution, and toxic wastes are harming the sustainable development of the planet and of the economic system. Although governmental policies have partially allayed many environmental problems and environmentally conscious individuals have contributed to a gradual modification of some consumption habits, the role of corporations is crucial for the achievement of ecologically sustainable development (Shrivastava, 1995c). A logical reason for this liability lays in the fact that companies are definitely the main source of environmental trouble. But a more important justification is the fact that companies have the financial resources, the technological knowledge, and the institutional influence to provide ultimate solutions.

In this perspective, the choice of product and production technologies represents the most powerful channel through which companies can try to contain their environmental impact (Shrivastava, 1995a).

Although companies have many options to reduce the environmental impact of their activities through product design and technologies, their initiative is often stifled from the evidence that market entrances of green products tend to be difficult, slow and highly requiring. One likely explanation is that existing production and consumption patterns are often 'locked-in', indicating that, independently from the effective superiority of existing technologies, various agents in the market do not have enough incentives to switch to alternative technologies. On the company side, firms maintain existing technologies because of: (1) competition dynamics and profit rates, which make the large investments in adapting the production process to environmental standards very risky; (2) the variability of governmental regulations, which change from country to country and from year to year, thus creating uncertainty on the correct environmental policy to be adopted by companies (Chen, 2001; Janssen and Jager, 2002). As to the consumer side, they procrastinate their switch to products incorporating environmental technologies because of: (1) performance conflict between environmental attributes and traditional attributes; (2) unawareness of the environmental burden of their consumption behavior; (3) disbelief in the solutions offered by alternative technologies; (4) social needs linking consumer satisfaction to social comparison and imitation when deciding what to consume (Chen, 2001; Janssen and Jager, 2002).

As a result, environmental technology adoption and use remains a central concern of research and practice in the field of environmental commitment. Despite impressive advances in the performance of green technologies and in the competitiveness of green products, the problem of underutilized green technologies persists. Understanding and creating the conditions under which environmental technologies will be embraced by companies and consumers remains a high-priority research issue.

The aim of this research is to explain the diffusion problems of green technologies through the lens of technological dominance (Anderson and Tushman, 1990; Clark, 1985; Dosi, 1982; Schilling, 1998; Suarez, 2004; Suarez and Utterback, 1995; Utterback and Abernathy, 1975; Utterback and Suarez, 1993). According to this literature "technological change can be fruitfully characterized as a socio-cultural evolutionary process of variation, selection and retention" (Anderson and Tushman, 1990) through which a dominant technology finally emerges. This process of selection is shaped by social, political, and organizational dynamics acting both at industry and firm level. Being green technologies disruptive (radical) innovations in each industry in which they are implemented, their full acceptance is subordinated to the repeated interaction of firm capabilities, managerial willingness, institutional rules and competitive dynamics. The purpose of this research is to shed light on the occurrence and the strength of these forces through an evolutionary approach (Nelson and Winter, 1982).

1.2 Theoretical background and research questions

Environmental technologies include all those technologies that reduce the negative impacts of products or services on the natural environment. More precisely, environmental technologies can be defined as all "production equipment, methods and procedures, product designs, and product delivery mechanisms that conserve energy and natural resources, minimise environmental load of human activities, and protect the natural environment" (Shrivastava, 1995, p.185).

Consistently with the definition, environmental technologies include both product and production technologies. So talking about the diffusion problems of products incorporating environmental technologies means talking about both products that are clearly green in their design and functioning, and products that have a traditional design but have been produced through cleaner production technologies.

The existing literature explored commitment to environmental technologies through two prevalent theoretical approaches: resource-based view and institutionalism.

According to the resource-based perspective, companies shift to environmental technologies because of their potential profitability through the development of specific rent-earning resources and capabilities (Bansal, 2005; Hart, 1995; Russo and Fotus; Sharma and Vredenburg, 1998). On the other side, the institutional logic suggests that the rate at which green technologies/environmental management diffuse among firms and markets is conditioned by social and normative pressures, which influence the perception of firms' acceptability and legitimacy (Hoffman, 1999; Jennings and Zandbergen, 1995).

Although each perspective provides useful distinct insights, the interaction and integration of them both could provide a better explanation of firms' commitment to environmental technologies (Bansal, 2005). This is consistent with that stream of researchers claiming that the sustainable advantage of a firm depends on its ability of managing the resource capital within the institutional context (Barney and Zajac, 1994; Oliver, 1997; Rao, 1994). The complementarity between rent-generating resources and institutional pressures is particularly relevant when firms' capability of generating sustainable competitive advantage is analyzed over time, as it happens in the case of the development and diffusion of green technologies.

As a consequence, the present research attempts to combine the two perspectives and observe their interaction over time by approaching the diffusion problems of environmental technologies through the lens of technological evolution (Anderson and Tushman, 1990; Clark, 1985; Dosi, 1982; Schilling, 1998; Suarez, 2004; Suarez and Utterback, 1995; Utterback and Abernathy, 1975; Utterback and Suarez, 1993).

Consistently with the concept of disruptive technology (Christensen, 1997), environmental technologies underpeform dominant technologies along the dimensions traditionally valued by mainstream customers. At the same time they offer superior performance in rising features at the moment only prized by a reduced fringe of customers (environmental conscious customers). Green technologies represent a discontinuity from the past, and technological changes need time to properly occur and to become established (Anderson and Tushman, 1990). Consequently, firms' capability of generating sustainable competitive advantage from green technologies and the subsequent affirmation of green technologies as industry standard require a certain time span.

During this technological cycle different evolutionary forces will contribute to the eventual emergence of green technologies as dominant design: firm capabilities and resources, institutional rules and pressures, competitive dynamics, and market preferences. This conforms to the existing school of thought stressing the importance of interaction between firm-level resources (Dierickx and Cool, 1989) and external factors (Dess and Beard, 1984; Hannan and Freeman, 1997: Porter, 1985). Irrespective of the size of the technological field, these two macro-groups of factors influence the outcome of a technology battle, being the choices made at one level necessarily reflected at the other level (Suarez, 2004; Utterbakc and Suarez, 1993).

The present study investigates this era of ferment in the diffusion of environmental technologies through the analysis of the forces acting at different levels of analysis. In particular, the dissertation intends to explore the following research questions:

- **How much time does a new product incorporating environmental technologies need to takeoff?**
- **Does the takeoff have any systematic pattern?**
- **Is the takeoff anticipated and followed by any systematic pattern in the interaction among evolutionary forces?**

1.3 Methodology

The conceptual definition of takeoff adopted in this study is "the point of transition from the introductory stage to the growth stage of product life cycle" (Golder and Tellis, 1997). Therefore, the point of takeoff is characterized by the first large increase in the new category. This phenomenon has been modelled by the hazard function in order to test the hypotheses of this study, following the suggestions of previous literature (Allison 1984, 1985; Cox 1972; Heckman and Singer 1984; Helsen and Schmittlein, 1993; Jain and Vilcassim, 1991; Kalbfleisch and Prentice, 1980; Lawless, 1982).

For fulfilling the purpose of the dissertation a database has been created using the historical method for data collection (Golder, 2000). The benefits of using the historical method include reduce self-report bias, use of longitudinal analysis to assess causality, and new insights from a fresh reading of history (Golder 2000; Tellis and Golder, 1996).

Two criteria have been used to select the industries for settling the study: the degree of technological innovativeness and the environmental impact. The research focuses on industries with a certain degree of technological innovativeness, intended as the frequency with which new technologies (disruptive and not) are introduced at product and process level. Additionally, industries with a relevant negative impact on the natural environment have been considered. On the basis of these criteria, the selected industries are: appliances, automotive, and lighting.

The information needed for this study is technical data on product performance and distinctive features of several technologies at different moments of industry evolution. The primary sources of data were reports in technical journals, industry publications, white papers published by R&D organizations, annual reports of industry associations, information bulletins released by firms, and general reports on environmental issues.

1.4 Structure of the thesis

Due to the fact that this dissertation deals with an interdisciplinary problem, the first two chapters after the introduction, have been dedicated to the bibliographical review of both fields of study on which the research is focused: corporate environmental commitment and technological adoption. Therefore, Chapter 2 concentrates on the discussion of the main theoretical and empirical contributions of the existing literature in the field of corporate environmental commitment. Chapter 3 attempts to provide an overview of the broad and cross-disciplinary field of technological innovation.

The meeting point between both fields of study is analyzed in Chapter 4, together with the theoretical framework and the hypotheses that will be used in order to answer to the research questions.

Chapter 5 illustrates the methodology used in this research, with details on the research design, the data collection stage, and the econometric model selected for testing the hypotheses.

Chapter 6 presents and discusses the empirical findings, with an analysis of the significant and non-significant relationship and some indications on limitations and future directions for the study.

Chapter Two

Corporate Environmental Commitment in Business Research

2.1 Introduction

Corporate environmental management (CEM) refers to the corporate effort to reduce the size of the "ecological footprint" of company's activities and products (Bansal, 2005). CEM includes two dimensions: environmental orientation and environmental strategy. Environmental orientation is the recognition by managers of the significance of environmental issues facing their firm, and environmental strategy is the extent to which environmental issues are integrated in a firm's strategic plans (Banerjee et al., 2003).

CEM is part of a broader managerial philosophy referred as *corporate sustainable development*. According to the World Commission on Economic Development (WCED), sustainable development "is development that meets the needs of the present without compromising the ability of future generations to meet their own needs"

(WCED, 1987: 43). Corporate sustainable development can be achieved through the contemporaneous implementation of CEM, corporate social responsibility, and value creation. Since their direct connection with performance has been widely recognized, corporate social responsibility and value creation have received much more attention in research and have been readily implemented by companies.

During the last decade, events like Rio de Janeiro Earth Summit and the resulting amplified awareness of the consequences of global warming stimulated academic interest into CEM. As a result, in 1994 the Academy of Management established its "Organizations and the Natural Environment" interest group, and many journals (*Academy of Management Review, Academy of Management Journal, Journal of Advertising, Psychology and Marketing, Long Range Planning, Journal of Marketing Management*) published special issues on sustainable development in general and environmental management specifically.

However, although the knowledge and the discussion have definitely increased, the research in the area of CEM has some shortcomings. First, a common and solid theoretical foundation of the issue is still missing. This is not surprising when we consider that research on environmental issues emanates from distinct subfields like strategy, organizational behaviour, organization theory, marketing, and others, which tend to have different conceptual bases. Theory developed separately in each of these subfields is not readily combinable. Secondly, there is scarcity of rigorous empirical studies, which is a consequence of the shortage of good data. This hinders the development of broad overarching research designs with results that will be widely applicable. Finally, environmental issues have great implications for our well-being, but there is uncertainty in the degree to which these issues influence (or do not influence) business research. One of the reasons could be the fact that the harmful implications of environmental misbehaviour have been recently confirmed, and it is natural that published articles in social science journals will lag. Another reason could be that publication incentives are skewed in business schools towards incremental additions to established knowledge. Thus, innovative research needs to become institutionalized before its takeoff.

The following paragraphs will discuss the main research areas and findings in CEM, with particularly attention to their implications for the development and diffusion of environmental technologies. The analysis begins with a description of the different managerial approaches to CEM and their repercussions on the type of environmental products and technologies developed. The discussion continues with the examination of the factors that drive companies to adopt CEM. Two alternatives approaches are proposed and compared, with the conclusion that they are complementary and their simultaneous consideration provides a better explanation of corporate commitment to environmental management. Finally, since the literature identified environmental marketing as one of the most important and effective parts of CEM, some of the key issues in this area will be reviewed.

2.2 Strategic approaches to corporate environmental Management

Corporate environmental management can be driven by three different managerial philosophies, characterised by different degrees of proactivity toward the environmental issue (Aragon-Correa, 1998): pollution control, pollution prevention, and product stewardship.

Pollution control

Pollution control refers to *end-of-pipe* solutions to corporate emissions and waste. In other words, companies attempt to reduce their footprint through a responsible control and disposal of the waste generated by their ordinary activities (Hart, 1995; Russo and Fotus, 1997). The adopted solutions have an *ex-post* nature, given that they do not modify corporate processes but rather act on their outcomes.

Given their simplicity, pollution control practices dominated environmental management for many years. When managers realized the negative impact of corporate operations on the natural environment, the easiest solution was to minimize or eliminate emissions and effluents through the use of pollution-control equipment.

Compliance is achieved primarily by the addition of pollution-removing or filtering devices to the existing assets. This does not require the firm to develop expertise or skills in managing new environmental technologies or processes. Thus the implementation of this policy is straightforward and leaves a firm essentially in the same resource and capability situation it was before the adoption of the policy.

As it was quickly understood, installing and managing pollution-control equipment is expensive and unproductive. Since pollution-control technologies are add-on equipment available to every company, there is practically no chance to turn their adoption into a source of sustainable competitive advantage. As a result, other approaches to environmental management and pollution abatement emerged, which are able to combine the reduction of environmental footprint and the generation of competitive advantage.

Pollution prevention

Pollution prevention consists in reducing emissions and waste through innovative processes or technologies applied to the production process (Klassen and Whybark, 1999; Russo and Fotus, 1997). The environmental technologies analyzed in the next chapters are an implementation of this policy. Differently than pollution control, this philosophy has a more proactive attitude towards the environmental issue, since it implies a re-thinking and re-designing of the corporate processes and, consequently, the development of new capabilities in order to achieve the environmental management objectives.

Pollution prevention thus appears analogous, in many respects, to total quality management (TQM); it requires extensive employee involvement and continuous improvement of emissions reduction, rather than reliance on expensive *end-of-pipe* pollution control technology (Hart, 1995)

The benefits in terms of cost reduction and increased efficiency are particularly significant at the beginning of the implementation of a pollution prevention policy. The sources of these benefits are several: savings in cost of "end-of-pipe" pollution control technologies; reduction of waste material and, consequently, more effective use of row materials and more effective production processes; faster and better compliance to the emissions requirements, with consequent saving in related liability costs (Christman, 2000; Hart, 1995; Klassen and Whybark, 1999; Russo and Fotus, 1997).

Opposite to pollution control technologies, pollution prevention technologies can be a source of sustainable competitive advantage. In fact, being idiosyncratic to the production process to which they are applied, prevention technologies are not easily imitable by competitors.

Product stewardship

Product stewardship refers to the corporate effort to reduce the ecological footprint of products *from cradle to grave*. This philosophy moves the attention from processes to products, since it points to a rethinking of the entire development of new products. In fact, the corporate ecological footprint is reduced not only through the adoption of new environmental friendly processes, but also through designing products in a way that they require less materials (toxic or not) and are able to be disassembled for recycle and reuse at the end of their life.

Product stewardship takes pollution prevention a step forward, since it integrates environmental commitment into product design and development process. As a result, companies develop and commercialize products whose environmental burden is reduced during their entire life-cycle (*from cradle to grave*). Specifically, "for a product to achieve low life-cycle environmental costs, designers need to: (a) minimize the use of non-renewable materials mined from the earth's crust; (b) avoid the use of toxic material; (c) use living (renewable) resources in accordance with their rate of replenishment;" (Hart, 1995) (d) have a low environmental impact production process; and (e) be easy to decompose and recycle at the end of its useful life.

Product stewardship could be a preferred strategy for start-up firms given the fact that they are not bound to any previous product, facility, or manufacturing process. Early embracing of product stewardship could offer opportunities for niche strategies and could represent an important source of sustainable competitive advantage.

In general product stewardship can generate competitive advantage through competitive pre-emption of resources, partnerships, and reputation: it offers companies an opportunity for differentiating from competitors and for becoming the first entrant in new green product domains. (Hart, 1995). Additionally, product stewardship has the potential of generating differentiation advantage through practices like redesigning packaging and products in more environmentally responsive ways, deploying new environmentally responsible products, and advertising the environmental benefits of the products (Christmann, 2000). Differentiation advantage creates the potential to increase product prices, which results in higher revenues. Empirical studies show that revenues enhancement is the main economic motivation and the desired outcome of implementing best practices focusing on product characteristics and markets (Stead and Stead, 1995)

Obviously this strategy implies a higher commitment in terms of management and resources, since its success requires an organizational ability not only to coordinate functional groups within the firm, but also to integrate the perspectives of key external stakeholders - environmentalists, media, community leaders, regulators - into decisions on product design and development. In particular, Hart (1995) suggested that firms will only be able to successfully adopt product stewardship strategies and achieve differentiation through environmentally responsible products if they have first made significant progress in the implementation of pollution prevention technologies, which are process-focused practices. Thus, process-focused best practices can be seen as the basic precondition for the implementation of all best practices of environmental management and as the most basic building block of a responsible environmental strategy.

Regulators have increasingly supported the product stewardship approach. For example, in the 90s the German government proposed the first product "take-back" law, according to which for selected industries (such as automobiles), customers were given the right to return spent products to the manufacturer at no charge. In turn, manufacturers would be prevented from disposing of these used or 'junk' products. The spectre of this law created a tremendous incentive for companies to learn to design products and packaging that could be easily composted, reused, or recycled in order to avoid what would be astronomical disposal costs and penalties (Hart, 1995).

2.3 Drivers of corporate commitment to CEM

According to the existing literature, corporate commitment to CEM can be explained through two different theoretical approaches: resource-based and institutional.

As stated by the resource-based perspective, companies devote to green technologies because of their potential profitability through the development of specific rent-earning resources and capabilities (Bansal, 2005; Hart, 1995; Russo and Fotus, 1997; Sharma and Vredenburg, 1998). On the other side, the institutional logic suggests that the rate at which environmental management diffuses among firms and markets is conditioned by social and normative pressures, which influence the perception of firms' acceptability and legitimacy (Hoffman, 1999; Jennings and Zandbergen, 1995).

2.3.1 Resource-Based View of the Natural Environment

The resource-based view of the firm (RBV) argues that effective corporate strategies build rent-earning resources and capabilities. Firm resources can include tangible assets, such as the firm's financial reserves, physical plant and equipment, and its raw materials; and intangible assets, such as the firm's reputation, culture, and intellectual capital (Grant, 1991). Capabilities are the skills that firms develop to reproduce and manage these resources. The rent-earning potential of a firm's resources and capabilities are determined by their scarcity, uniqueness, durability, inimitability, and non-substitutability, which ultimately determine the firm's competitive advantage (Barney, 1995; Dierickx and Cool, 1989; Peteraf, 1993). These resources and capabilities are acquired in imperfect factor markets, and over time they develop further by the growth and resource acquisition paths taken by the firm (Barney, 1986; Teece, Pisano, and Shuen, 1997). As a result, the firm's resources and capabilities are path-dependent.

As claimed by RBV arguments, companies embrace CEM as a way to accumulate valuable and distinctive resources and capabilities, which in turn lead to sustainable competitive advantage and superior firm performance (Christmann, 2000; Hart, 1995; Majumdar and Marcus, 2001; Marcus and Nichols, 1999; Russo and Fotus, 1997; Sharma and Vredenburg, 1998; Shrivastava, 1995c).

Corporate environmentalism offers competitive advantage by significantly lowering costs in the long run or helping differentiate products and services (Porter and van der Linde, 1995)

The drivers to CEM identified by the RBV of the natural environment include a range of strategic attributes that can be consciously managed by an organization to attain superior performance. Researchers attempt to identify these attributes and describe the context in which their presence or absence influences a firm's environmental impacts. The most important are described in the next paragraphs.

Pollution prevention technologies

Besides being a best practice in environmental management, pollution prevention technologies have been identified as a source of competitive advantage for companies committed to environmental management and successful in their development (Christmann, 2000; Hart, 1995; Russo and Fotus, 1997). Pollution prevention technologies have the potential of generating cost advantages to companies. In fact, they improve production efficiency in many ways: through the reduction of input costs due to better utilization of inputs, through savings from recycling or reusing materials, or through the reduction of waste disposal costs. Pollution prevention technologies can reduce production cycle time by simplifying or eliminating unnecessary steps in production process or by the use of higher-quality and environmental friendly equipment. Finally, pollution prevention technology progressively cut emissions quite below required levels, thus decreasing compliance and liability costs.

In most of the cases, pollution prevention technologies are difficult to imitate, since they are strictly connected with the production specificities of the company developing them. As a result, they are able to provide a sustainable cost advantage (Barney, 1991; Wernerfelt, 1984). On the contrary, pollution control solutions are simply add-on technologies available on the market to all the companies. Consequently, they are easily imitable and unable to generate a sustainable competitive advantage.

Environmental Innovativeness

Environmental innovativeness refers to company capability and willingness to develop innovations related to environmental management. Some authors use the label of environmental responsiveness or proactiveness to indicate the same concept, and argue that it can lead to the development of certain capabilities that can represent a source of competitive advantage (Aragón-Correa, 1998; Aragón-Correa and Sharma, 2003; Hart, 1995; Henriques and Sadorsky, 1999; Sharma and Vredenburg, 1999).

More specifically, environmental innovativeness implies allowing the organization to shift away from current practices, in which environmental considerations are considered secondary, and develop new, more encompassing practices, in which environmental impact plays a more central role. Looking explicitly at environmental technologies, innovativeness is prevalently connected to pollution prevention technologies, which can lead improved environmental performance of any kind - it can be limited to design and manufacturing issues (Christmann, 2000), or it can encompass far-reaching issues such as development of new markets and new means of sustainably servicing existing markets (Hart and Milstein, 1999; Senge and Carstedt, 2001). The core of these arguments is that thinking outside the box, while being aware of environmental issues, will lead to improved environmental performance, which will generally be aligned with improved financial performance over time. Additionally, the capability of "thinking outside the box" is unique and difficult to imitate not only in the environmental strategy domain. Thus, it unquestionably represents a source of sustainable competitive advantage.

Organizational slack

Organizational slack refers to company resources in excess of those needed for output production, and which can be used to adapt to internal pressures for adjustment or to external pressures for change. Generally speaking, a reduced slack is associated to lower environmental performance (Bansal, 2005). Given that many companies do not consider environmental management a top priority yet, when the slack is low it is employed to address other issues that are more urgent in the mindset of top management (Henriques & Sadorsky, 1996). Since in many cases environmentally related actions are pursued at the discretion of managers, it is reasonable to assume that if managers have more discretionary slack at their disposal, they can better view environmental issues as opportunities, rather than as threats (Bowen, 2002; Sharma, 2000; Sharma, Pablo, and Vredenburg, 1999), thus adopting a more proactive environmental strategy.

Workforce perceptions

The way organizational members perceive environmental issues is crucial, especially with reference to top management. In general, enhanced employee awareness of environmental issues leads to improved individual behavior and practices (Jiang and Bansal, 2003). However, individual concern for an issue is not enough; it must also be congruent organizational values. That is why the role of top management is particularly important (Aragón-Correa, Matías-Reche, and Senise-Barrio, 2004).

When environmental issues are perceived positively, as opportunities for business development and growth, rather than negatively, as threats, companies will exhibit more progressive environmental strategies (Sharma, 2000). The way managers perceive environmental issues is dependent on their understanding of the issue along three dimensions: monetary loss-gain, uncontrollability-controllability, and overall negativeness-positiveness (Sharma, Pablo, et al., 1999). This multidimensional cognitive categorization is what drives managerial attitudes toward an environmental issue and determines its salience.

2.3.2 Institutionalism and the natural environment

The central argument of institutional theory is that organizations strive to maintain their legitimacy by conforming to the expectations of their stakeholders (Aldrich and Fiol, 1994; DiMaggio and Powell, 1983; Scott, 1995). By following institutional prescriptions, firms reflect an alignment of corporate and societal values. Thus, concern over legitimacy pushes firms to adopt managerial practices that are expected to have social value (Deephouse, 1999; Scott, 1995).

Institutional arguments suggest that commitment to CEM is stimulated by the firm effort to maintain its legitimacy. Firms attempt to reduce the environmental footprint of their products and process because of the increasing pressure coming from governmental regulation, media attention, and environmental activism (Bansal, 2005; Bansal and Clelland, 2004; Hoffman 1999). In fact, given the increasing relevance of the issue, regulations and international agreements on environmental commitment are flourishing. Additionally, many stakeholders with different opinions on the environmental responsibilities of the company are participating into the debate and pushing towards the approval of norms and the infiltration of common believes. As a result, the individual judgement on environmental commitment is becoming a more and more influential determinant of firm's acceptability and legitimacy in the eyes of potential customers.

Environmental legitimacy can generate several advantages in those industries where the environmental issue is particularly relevant. For example, legitimacy enhances corporate reputation, which in turn improves corporate relationships with different stakeholders. Legitimate companies will have easier access to environmentally committed partners and suppliers, thus obtaining better exchange conditions and, consequently, cost savings to eventually reinvest in environmental-related activities (Bansal and Clelland, 2004; DiMaggio and Powell, 1983). Additionally, environmental legitimacy reduces the risk in introducing new environmental friendly products, since the success of previous introductions and the company reputation lower customer uncertainty in industries in which environmental technologies are already present (Sherer and Lee, 2002). Environmental legitimate firms also run less risk of environmental accidents and, consequently, of costly legal sanctions and remediation costs (Godfrey, 2005; Khanna and Damon, 1999; Sharma and Vredenburg, 1998; Shrivastava, 1995b). Limiting impact on natural environment also protects firms from continuous stakeholder examination and thus reduces the risk of social sanctions like boycotts or negative press attitude (Oliver, 1991). Environmentally legitimate firms can attract and maintain better partners, customers, and employees than poor performers, given the increasing relevance of environmental commitment as decisional criteria for these stakeholders (Buysee and Verbeke, 2003; Henriques and Sadorsky, 199; Sharma and Henriques, 2005; Turban and Greening, 1997). Lastly, environmental legitimacy reduces idiosyncratic firm risk. Bansal and Clelland (2004) showed that environmentally legitimate firms experience lower unsystematic stock market risk than less legitimate firms, so they have a lower cost of capital. In sum, firms are likely to recognize the value of conformity to environmental expectations, as the resultant legitimacy reduces the probability of organizational failure (Scott, 2005; Singh, Tucker, and House, 1984) and may enhance financial performance (King and Lenox, 2002; Klassen and McLaughlin, 1996).

Institutional pressure towards CEM has three main sources: governmental institutions, competitors in the industries, and other influential players in the organizational field (consumers, third associations, actors in the value chain). The institutional pressure by each player can have different strength and act in a coercive, mimic, or normative way.

Government pressures

Governments can control the environmental commitment and conduct of firms under their jurisdiction by imposing and enforcing environmental regulations (Bansal, 2005; Christmann, 2004). Environmental regulations and costs can shape the strategic decisions o designing new product technologies, sourcing new raw materials, locating production facilities, managing energy and wastes. Governmental institutions at different levels (regional, national, international, EU) have developed, and continue to develop, systems of fines and penalties for those companies not complying with the established rules on reduction of ecological footprint. Since the lack of conformity to the established norms can determine monetary loss, damaged reputation, or even loss of the licence to operate, governmental pressures are regarded as particularly effective in shaping company environmental actions. In this case the type of pressure is mainly coercive, but it also incorporates a normative/cognitive element, partially determined by the political culture that prevails in the organizational field and also in the geographic location. Specifically, the societal values and the governance habits of a certain organizational field (or geographic area) shape the regulatory policy, creating a *regime*. Pro-environmental regulators that emphasize negotiation with companies will lead to a different regime than, for example, regulators that emphasize strict enforcement but do not consider the environment a high priority (Jennings and Zandbergen, 1995). For instance, the U.S. environmental legislative framework is a typical example of the sanctioning method of enforcement within a very centralized command-and-control framework. In the United States, the federal government has a range of sanctions that it can use against corporations and individuals to encourage them to comply with environmental laws. These sanctions come through the top-down system set up by the federal government. The Environmental Protection Agency (EPA) was established in 1970 as the independent agency responsible for establishing and enforcing the environmental standards and for maintaining consistency among national environmental goals. Local states have only been free to legislate new standards and means of compliance within the established national norms. In contrast, the Canadian framework has been dominated by a command-and-control framework with different layers of administration, each employing a conciliatory, consensual, and consultative method of enforcement.

Although opponents argue that environmental regulation hurts the world economy and slows down economic growth, empirical studies have identified regulatory pressures as a main determinant of firm's domestic environmental conduct in various industries

(Dasgupta, Hettige, and Wheeler, 2000; Henriques and Sadorsky, 1996). Porter (1991, 1994) suggests that strict environmental regulations do not inevitably hinder competitiveness against foreign rivals. They may even enhance competitiveness, since higher environmental standards can trigger innovation and upgrading of technologies. On the same line, Banerjee et al. (2003) provided empirical support to the fact that environmental legislation is the most important incentive for developing pollution prevention strategies. In order to be a driver for environmental innovation, regulation should be strict, stable, and predictable; it should have a preventive approach; and it should incorporate industry participation during the design process (Porter and van der Linde, 1995).

Industry pressure

Industry pressure can come from industry associations, competitors' actions, etc (Christmann, 2004; Hoffman, 1999). Their strength in shaping industry norms comes from their capability of defining the legitimacy requirements to which all the players of a certain industry should conform. The institutional pressures can be mimic or normative in nature.

Mimic dynamics imply that the behaviour of competitors drives corporate willingness to adopt higher environmental standards. When several players in an industry increase their efforts towards CEM, it is more likely that imitative behaviours occur among competitors. In other words, if a practice comes to have some recognized value or is believed to be a new industry standard - such as recycling of parts in the auto industry or recycling of printer cartridges in business offices - the organization will simply mimic similar organizations in the industry rather than questioning the practice's value.

There are two main explanations for mimic dynamics. The first one is the uncertainty reduction determined by the fact that more and more players are engaged in the same practices. Legislation on environmental issues is still characterized by a high level of variety, uncertainty and confusion (changing expectations, complexity of the problem, and difficulty of its resolution). In many cases companies justify their incompliance to norms with the lack of clarity and consistency on the suggested practices. Following the behaviour of other industry players allows companies to benefit from the experiences of their peers and reduce the uncertainty on the most appropriate behaviour.

The second explanation is related to the fact that adopting certain environmental practices or standards can become a source of competitive advantage for early adopters. Imitative behaviours can be triggered by the threat of the consequences of being a late adopter, including cost, procurement, and reputation disadvantages. A related example is the market introduction of the hybrid car in the automobile industry. Before its introduction, car companies distributed their research efforts among different environmental-friendly solutions. Once Honda and Toyota introduced the hybrid car into the mass market, most of their competitors invested (or accelerated their investment) in the hybrid technologies in order to be able to add hybrid models to their fleet.

Although mimicry prevails in industry dynamics, normative pressures can also occur, as in the case of *Voluntary Environmental Initiatives* (VEI) (Christmann and Taylor, 2002). VEIs are emerging as a new tool for business self-regulation. The term “voluntary” refers here to initiatives that are not directly mandates and enforced by governments. Firms decide for themselves whether or not to adopt international VEIs and to adhere to their requirements. Supporters of VEIs believe that they embody a new model for corporate oversight that compensates for potential weaknesses of national governments to regulate corporate environmental conduct effectively in the global economy. Examples of successful VEIs are: the ISO standard 14001; the Eco Management and Audit Scheme (EMAS) and the Eco-label from the European Community; the adoption of the OECD Guidelines for Multinational Enterprices.

Other institutional pressures

The last source of institutional pressure includes consumers, media, and environmental activists.

Consumers. This type of pressures descends from the fact that customers increasingly consider environmental factors in their purchasing decisions (;Christmann, 2004; Christmann and Taylor, 2001; Henriques and Sadorsky, 1996). Consumers may act directly to curtail organizational activities perceived as damaging, or, indirectly, by rallying allies to action (Frooman, 1999). Although the customer is generally seen to be a key actor, firms might assume that in many cases consumers actually have very little knowledge about environmental issues, as well as low awareness or low level of prioritization (Fineman and Clarke, 1996; Foster and Green, 2000), so that "playing the environment card" might not be an effective marketing strategy. The *green consumer* remains an elusive demographic, if indeed such a demographic even exists (Pedersen and Neergaard, 2006). Multinational corporations tend to respond to perceived customer pressures with public relations strategies and standardization of their environmental communication rather than by self-regulating their environmental conduct (Christmann, 2004), suggesting that consumers are indeed not very knowledgeable and are prone to have their perceptions manipulated.

Media attention. A firm's reputation for environmental responsibility with its customers is based on the information about the firm's environmental conduct that customers can obtain. That is why media attention is a key variable in determining CEM. The positive effective of media attention on corporate commitment to CEM has been shown by several previous studies (Bansal, 2005; Bansal and Clelland, 2004; Bansal and Roth, 2000; Bowen, 2000; Henrique and Sadorsky, 1996). The relevance of environmental issues in the media and the threat of negative media coverage act as powerful coercive determinants of corporate behaviour. Negative coverage can easily damage company reputation and, consequently, affect company revenues in case in which environmental interest groups or other stakeholders decide to react.

Activists. Activists can be characterized as persons lobbying for change "based on value objectives rather than strict material interests" (Wade-Benzoni et al., 2002: 46), connecting the values of their cause with their self-identity. Activist organizations will tend to be adversarial toward firms that are perceived as hostile and disaffected, but will seek cooperative relationships with firms that are proactive.

Christmann and Taylor (2002) discussed the role of NGOs in shaping the environmental commitment of multinational companies. NGOs act on behalf of a broad range of social and environmental interests. In the past ten years, the ability of NGOs to exert global influence on firm conduct has increased tremendously. Because NGOs have mobilized cross-nationally, globalization provides seemingly limitless opportunities for NGOs to play a role in filling the gaps arising in a world where legal and political structures are still primarily organized at the level of the nation state. NGOs have changed their strategies from focusing on legal and policy-making processes to also focusing on firms' environmental conduct. NGOs monitor corporate activities and publicly target firms using a variety of techniques ranging from street demonstrations to articulated position papers and sophisticated public relations campaigns. NGOs also influence the behaviour of customers in the marketplace by articulating environmental concerns and framing alternatives. Many NGOs enjoy high credibility among consumers, who are increasingly sceptical of information released by companies. NGOs can damage corporate reputations and contribute to loss of customer approval.

2.4 Top management commitment

Besides RBV and institutional explanations of CEM, the extent to which top management convictions, values, energies, and innovativeness support environmentalism is a powerful driver for corporate environmental commitment (Banerjee et al., 2003; Drumwright 1994; Starik and Rands 1995). There are multiple reasons why competitive advantage is not sufficient to devote companies to the implementation of environmental practices and the development of green technologies. One of the reasons is related to the fact that environmental investments are still risky and do not always guarantee short-term profits (Hart, 1995; Hart and Ahuja, 1996; Sarkis and Cordeiro, 2001). On the other hand, there is empirical evidence that good environmental performance has a long-term effect on the overall economic performance of the company (King and Lennox, 2002; Klassen and McLaughlin, 1996). In these circumstances only a strong and committed leadership can motivate the company to modify its practices and production activities with the awareness that the profitability will follow only in the long term.

Strong environmental leadership is critical also in the case of industries characterized by stringent environmental regulation or strong public concern. In the first case the top management has the authority to promote the implementation of practices that are oriented not only to regulation compliance but also to pollution prevention (Agle, Mitchell, and Sonnenfeld, 1999). In the second case, since CEOs are particularly concerned about public opinion, they easily become endorser of visible environmental friendly actions (Drumwright, 1994).

The link between top management commitment and corporate environmental committed has been tested by many studies. Cordano and Frieze (2000) and Flannery and May (2000), using theory of planned behavior, focused on managers' attitudes as an important antecedent to preferences for source reduction activity. Sharma (2000) showed that, even in an industry subject to strong institutional pressures (such as the oil and gas industry), managers exercise strategic choice by undertaking environmental strategies. These strategies were associated with managerial interpretations of environmental issues as threats or as opportunities (Sharma, Pablo, and Vredenburg, 1999; Slater and Angel, 2000)

Top managers show their environmental commitment in many ways. For example, they appoint senior managers responsible for supervising the firm's environmental orientation and strategy, or they introduce environmental management systems that allow companies to officially fix environmental targets and monitor their achievement. Additionally they can lobby or form alliances with governmental agencies, other companies, or non-profit organizations in writing regulations that will ultimately affect the business.

2.5 Environmental marketing strategy within CEM

Besides being implemented at a corporate level, environmental commitment can be put into practice at a functional level. In this regard, environmental marketing strategy has captured the interest of the researchers due to the relative promptness with which it can be implemented.

In their empirical study of antecedents of corporate environmentalism, Banerjee et al. (2003) found that the impact of public concern on environmental marketing strategy was higher than its impact on environmental corporate strategy. This bias toward environmental marketing strategy may be based on the firm's ability to obtain immediate and quick benefits by implementing environmental marketing strategy as opposed to environmental corporate strategy. This is consistent with prior findings, according to which environmental marketing strategies, such as green niche marketing strategies (Porter and van der Linde, 1995; Shrivastava, 1995) and consumer-oriented green advertising strategies (Banerjee, Gulas, and Iyer, 1995), are lucrative and easier to implement.

Varadarajan (1992) introduced the term *enviropreneurial marketing* as "environmentally-friendly marketing practices, strategies, and tactics initiated by a firm in the realm of marketing: (1) to achieve competitive differentiation advantage for the firm's offerings vis-à-vis competitors' offerings, and (2) influenced by the firm's views on the duties and responsibilities of a corporate citizen" (p.342). Enviropreneurial marketing does not exist in isolation, but instead flows from an organization-wide philosophy that places the physical environment among the top concerns and potential differentiating factors of the firm. However, the environmental responsiveness of the marketing department is capable of reflecting quickly the broader vision of the firm.

Specifically, the marketing function can rapidly implement the corporate environmental strategy through the use of the following marketing-mix actions: politics of green product design; distribution with green criteria; pricing of green products; green publicity, advertising and sponsoring (Rivera-Camino, 2007).

The study of the relationship between environmental performance and green products is still underdeveloped. However, the literature recognized that managers should be aware that environmental marketing begins with green design, and that product design represents an active interface with customers (Vasanthakumar, 1993). Green distribution is relevant because it has the task of taking the green products to the consumers and maintaining the ecological nature of them. Additionally, distribution often increases the environmental impact of products, and it is constantly regulated for environmental compliance (Rivera-Camino, 2007). Product pricing has been widely regarded as one of the reasons for the poor market performance of several environmental products: green product differentiation seems to be working only if green products reduce consumers' short term costs (Rivera-Camino, 2007). Similarly, consumers and industrial buyers can be influenced by advertising reflecting company's commitment to the environment (Polonsky and Ottman, 1998). Recent studies have confirmed this in various sectors including electronics, furniture, and the automobile industry (De Cicco and Thomas, 1999).

2.6 Research Gaps

Although the concept of environmental commitment has been deeply analyzed, limited attention has been given to its market performance implications. Specifically, in front of the poor market performance of green technologies, the key question of whether the market is capable of recognizing and rewarding the corporate environmental efforts has received inadequate answer. The relevance of finding an answer to this question is clear, from both a theoretical and pragmatic viewpoint. From the theoretical perspective, the RBV approach to environmental commitment claims that companies adopt environmental practises in order to develop resources and capabilities that can be source of sustainable competitive advantage and, thus, higher revenues. If on one side the existing studies attempted to identify these capabilities, on the other side there is no clarity and empirical proof of the mechanisms that turns them into competitive advantage and higher revenues. From a more pragmatic perspective, even if corporate environmental commitment can be implemented only because of the personal beliefs and willingness of the top management, there are few chances that the dedication of resources to environmental practices will be maintained in the long term if it does not generate sufficient revenues. As explained at the beginning of this chapter, environmental commitment cannot lead to sustainable corporate development if not coupled with value generation.

Given the relevance of understanding the link between environmental commitment and market performance, researchers have tried to understand the poor performance of environmental products and technologies by looking at demand side factors. Specifically, since consumers have been recognized as having a profound influence on companies with regard to product performance, product safety, and environmental impact (Porter, 1990), a lot of attention has been given to consumers' environmental consciousness as a driver of market performance of green products.

However, this research has not produced significant results for various reasons. First, although the customer is generally seen to be a key actor, in the case of environmental technologies he can often have very little and confused knowledge about environmental issues, as well as low awareness or low level of prioritization (Fineman and Clarke, 1996; Foster and Green, 2000). Additionally, the green consumer remains an elusive demographic: it is difficult to explicitly identify who they are, and it is even more difficult to transform their environmental attitude into a purchase behavior (Pedersen and Neergaard, 2006). Finally, the reason why demand-oriented arguments have not provided an explanation of the link between environmental commitment and market performance is that the phenomenon is much more complex and involves many more actors that simply a company and its customers.

Since the most direct indicator of market appreciation of environmental commitment is the market performance of green technologies developed by the committed company, the phenomenon could be regarded as a process of technological innovation adoption. This implies including in the analysis factors other than the demand side, and investigating the phenomenon with a time perspective and taking into account the role of several economic, social and organizational actors. To the knowledge of the authors no previous study has approached the issue of environmental commitment using a technological diffusion perspective. As shown in the chapter, past research has tried to describe the role of different stakeholders in determining environmental commitment, but none of them has focused on the most interesting issue of their role in influencing the market adoption of environmental technologies, and, consequently, environmental market performance. This is where this research attempts to make a contribution, as it will be further explained in the theory building session.

Charter Three

An Overview of the Research on Technological Evolution

3.1 Introduction

Since the late 1970s, technological innovation has been recognized as a key element affecting the dynamics and evolution of industries. As the technology of product and process evolves, the same happens to related systems of organizations, managerial practices, and external stakeholders.

At the theoretical and empirical level, it is possible to identify various streams of contributions that have highlighted different dimensions of technological innovation, industrial dynamics and industry evolution.

Since the late 1970s the "SPRU tradition" has largely advanced the understanding of the role of technological innovation in the evolution of many industries. It has provided empirical evidence on the multidimensional nature of the relationship between technological innovation and industrial change, on the influential role of several actors, on the alternation between periods of great uncertainty related to radical innovations and periods of more incremental technical change, and on the changeability across industries (Pavitt, 1984; Freeman and Soete, 1997; Dosi, 1988).

Complementary to this stream, since the late 1970s several studies have characterized the technological evolution of many industries as a life cycle including the following stages: the introduction of a radical innovation generally lead by small new producers, a period of demand growth, a greater emphasis on process innovations and a selection process which ultimately leads to a concentrated market structure (Abernathy and Utterback, 1978; Utterback, 1994; Utterback and Abernathy, 1975). The competitive landscape and the survival of firms within an industry depend on the evolutionary pattern followed by the technology, and especially on the emergence of what Utterback and Abernathy (1975) define as *dominant design*.

However, looking at the supply side of technological evolution is not enough, since empirical evidence convincingly indicated that, although the pattern is generally common, each industry is characterized by specific technological, economic, institutional, and market dynamics (Klepper, 1997; Geroski, 2003). The institutional approach broaden the discussion on technological evolution by focusing the attention on institutional dynamics in the setting of technological standards – namely, the actions by which different actors in the technological field (companies and institution) define, legitimize, combat, or co-opt rivals in order to succeed in their institutional projects (Scott, 1994). The main assumption of this stream of the literature is that the characteristics of the technology do not provide by themselves an exhaustive explanation of the path of technological progress. Rather than considering technology as an autonomous force or as driven by restricted group of companies, the institutional perspective argues that technology evolves through the combination of actions of companies and external actors (organizations) influencing the technological community (Tushman and Rosenkopf, 1992).

More recently, technological innovation and industry evolution have been examined within the framework of sectoral systems of innovation (Malerba, 2002, and 2004). This stream emphasizes collaborative dynamics among actors rather than competitive reactions as the main driver of technological evolution. Accordingly, technological innovation in industries is the result of the interaction of different actors (firms, universities, public agencies, financial organizations…) that have collaborative relationships of formal and informal types and have actions strongly influenced by firms' competences and learning processes and by the specific knowledge base of industries.

Additionally, some researchers in the marketing field focused their effort on the comprehension and modelling of the market diffusion pattern followed by the new technology (Golder and Tellis, 1997, 2004; Tellis, Stremersch, and Yin, 2003). As stated by these studies, predicting the turning points of takeoff and slowdown of a new technology is fundamental for driving companies' decisions and investments. Only after identifying them researchers will be able to understand the evolutionary factors shaping the different stages of the diffusion of the new technology.

A more exhaustive review of all the above-mentioned technological innovation studies reveals that scholars have made a wide range of more specific discoveries in the areas. Taking different perspectives on the details of the technological innovation phenomenon, empirical researchers have produced a variety of findings. In an effort to integrate theoretical contributions and empirical observations into a sharper analytical framework, it is useful to organize the different perspectives along the following three dimensions: definitions of core concepts, the temporal sequencing of technological development, and the casual mechanisms.

Additionally, the outcomes of technological evolution research will be contextualized in the particular case of environmental technologies. Given the scarcity of theoretical and empirical studies incorporating an ethical dimension into industry and technology dynamics, the present research will propose certain propositions that will be further developed in the following chapters.

3.2 Definition of core concepts in technological evolution

Various concepts have been developed in relationship with the dynamics of technological evolution.

The concept of *technological guideposts* has been introduced by Sahal (1981). It refers to major technological advances that are capable of setting a direction to be followed by more incremental innovations. In this framework, technological guideposts are chosen among various alternatives essentially by chance.

Similarly, Dosi (1982) referred to the same phenomenon with the concepts of *technological paradigms* and *technological trajectories*. A technological paradigm is defined as "a 'model' and a 'pattern' of solution of selected technological problems, based on *selected* principles derived from natural sciences and on *selected* material technologies" (Dosi, 1982, p.152). Thus, the paradigm is what marks technological change. Technological trajectories indicate the patterns of progress followed by the new technology introduced by a new paradigm.

Both Dosi's and Sahal's concepts are related to Clark's notion of *design hierarchies* (Clark, 1985). Accordingly, the technological evolution of an industry is the result of a process of interaction between the design of products incorporating the new technology and customer preferences. The company's choice of a core technical concept establishes the agenda for technological development; customers' preferences determine the hierarchy of technical problems to be solved.

The outcome of the interaction between technical and market counterparts is the dominant design in a certain technological domain. Different scholars have defined the concept of dominant design in different ways. Abernathy (1978) and Sahal (1981) adopted a very simple definition of dominant design as a single architecture that establishes dominance in a product class. Anderson and Tushman (1990) provided a quantitative definition of dominant design, in an attempt to facilitate its identification. Specifically, dominant design is a design that acquires more than 50% market share. Other authors prefer to define dominant design as the outcome of an evolutionary process in a technological field. According to Utterback and Suarez (1993), a dominant design is "the creative synthesis of the available technology and the existing knowledge about customer preferences" (p.7). Alternatively, a dominant design emerges when one or both of the following events occur: (a) there is a clear sign that the most closely competing alternative design has abandoned the active battle, thus acknowledging defeat directly or indirectly; (b) a design has achieved a clear market share advantage over alternative designs and recent market trends unanimously suggest that this advantage is increasing (Suarez, 2004). Although the core concept does not change, it is interesting to notice how across the years the process of emerging of a dominant design has been characterized as increasingly complex in terms of the actors involved. If the first researchers limited the process of interaction to only technical aspects of design and customer preferences, more recent investigation has tested the theoretical and empirical relevance of other actors like institutions, competitors, supply chain, etc.

Finally, another concept often associated to technological change is technological disruptiveness (Christensen, 1997; Christensen and Bower, 1996; Christensen and Raynor, 2003; Abernathy and Clark, 1985; Adner ,2002; Charitou and Markides, 2003). Disruptive new technologies are technological discontinuities sharing the following characteristics:

- Products incorporating the disruptive technology underperform on the attributes mainstream customers value at the time of their introduction.
- The mainstream customers do not value the new features offered by the technological innovation at the time of their introduction.
- Products incorporating the disruptive technology typically are more simple and cheaper than existing products
- At the time of its introduction, the technological innovation appeals to a low-end, price-sensitive customer segment, thus limiting the profit potential for incumbents
- Over time, further developments improve the technological innovation's performance on the attributes mainstream customers value to a level where products incorporating the technological innovation begin to attract more of these customers.

3.3 Temporal sequencing in technological evolution

In the attempt of characterizing the time pattern followed by a new (disruptive, discontinuous) technology entering a market (an industry), the S curve largely emerged as the most appropriate shape for describing the phenomenon (Foster, 1986; Sahal, 1981; Utterback, 1994a). When plotted against time, the market performance of the new technology goes through an initial period of slow market growth, followed by one of fast market penetration, and culminating in a plateau. These represent the three major stages of the S curve: introduction, growth, and maturity (see Abernathy and Utterback 1978; Utterback 1994a).

Introduction stage

When a new technological innovation enters a market (industry), its progress is generally slow and uncertain. The technological field is generally characterized by a high degree of variation in the way in which the technology is used and implemented by the introducing companies. Since the success of the new technology depends on its capability of surviving this turbulent stage, lots of research has been produced on identifying the reasons for this trouble.

The research stream on innovation diffusion started by Rogers (1995) highlights the market side and customers' lack of familiarity with the new technology as a possible explanation. During the introduction stage, potential customers are confronted with a high degree of uncertainty. When customers experience a new technology, they often miss the conceptual framework to evaluate its potential functionality and performance; thus, they delay the purchase decision. On one side they are often locked-in with the established technology and the switching costs can be very high for them. On the other side, the fact that at this stage customers are confronted with competing versions of the new technologies makes the adoption decision risky (Anderson and Tushman, 1990; Clark, 1984). As a consequence, the majority of potential adopters postpones the adoption to the moment in which an industry standard clearly emerges.

Technology novelty for the company is another determinant of the ferment characterizing the introduction stage. On the company side, technological novelty requires certain basic but important bottlenecks to be overcome before any new technological platform can be adopted and translated into practical and meaningful improvements in product performance. For example, the reluctance to commit to the development of a disruptive technology at its early stages can be explained with the unwillingness to cannibalize existing technology investments (Kamien and Schwartz, 1982); organizational inertia (Hannan and Freeman, 1977); and the inability to develop the necessary skills required to develop and manage the new technology (Bower and Christensen, 1995; Henderson and Clark, 1990; Leonard-Barton, 1992).

Furthermore and as a result of the two dynamics described before, the introduction of a radical technological advance triggers what Anderson and Tushman (1990) define as an *era of ferment*, during which the smooth take off of the new technology is hindered by the defensive efforts of existing technologies and the competition among different designs within the same technological regime. Leveraging on customer inertia and the imperfection of a technology at its infancy, incumbents try to maintain the established technological order by increasing the innovativeness of the mainstream technology and the efficiency of the production processes (Christensen, 1997). At the same time, a process of design competition within the new technological platform slows down market growth. During the era of ferment, several versions of the breakthrough technology appear, both because the technology is not deeply understood yet and because each pioneering firm has an incentive to support its variant against rivals. As a result, the era of ferment is characterized by a high number of competing variants of products incorporating old and new technology, thus shrinking the market penetration of each of them.

Growth stage

The beginning of the growth stage is usually associated with the appearance and consolidation of a dominant design from the competing variants of the new technology (Anderson and Tushman, 1990; Utterback, 1974). The dominant design is the tangible outcome of a temporary equilibrium reached by manufacturers, suppliers, customers, and regulatory agencies in order to decrease the uncertainty associated with the variation during the era of ferment.

The consensus on the dominant design begins an era of intensive progress along the technological trajectory started by the new technology, which leads to a progressive advancement of the technological frontier in the industry (Dosi, 1982). Using Christensen terminology, the increased number of developers contributes to advance the performance threshold of the new technological platform in both the disruptive and mainstream attribute. As a results, market uncertainty progressively decreases and the new technology begins appealing and penetrating a broader share of the market. As the emergence of a dominant design reduces product-class confusion and product cost, sales of products based on the new technology peak, thus boosting revenues and profits and offering further support for research (Klepper 1996).

Additionally, a dominant design has the effect of enforcing standardization so that production economies can take place. In fact, in most of the cases the dominant design is a synthesis of the needs of many classes of users of a certain product. Thus, the dominant design is appealing to a broader target segment, even though it may not meet the needs of a particular class to quite the same extent as a customized design.

Maturity stage

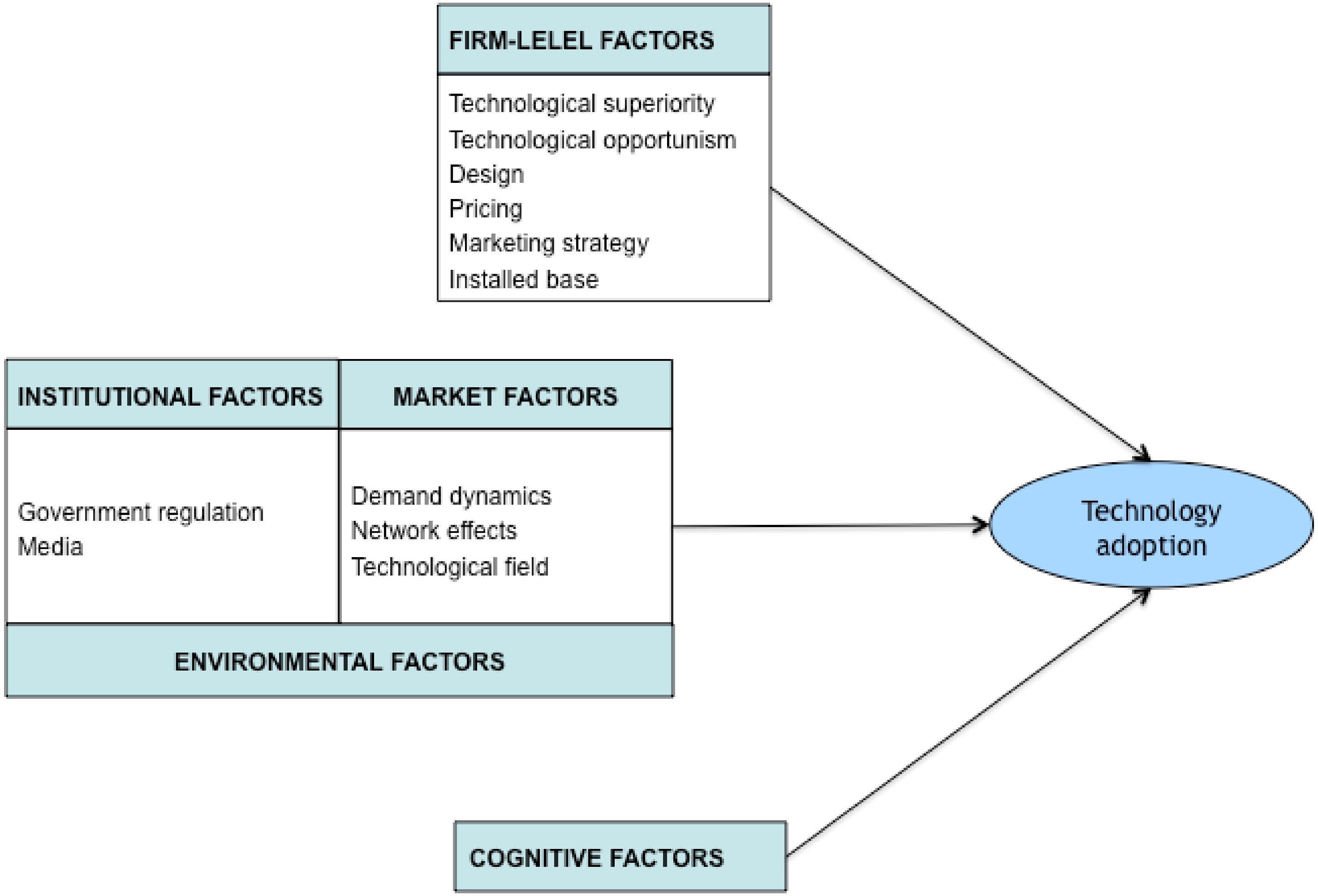
After a period of rapid improvement in technical performance and growth in market share, the new technology reaches the stage of maturity, during which progress occurs slowly or reaches a ceiling and market penetration remains stable (Brown 1992; Chandy and Tellis, 2000; Foster 1986; Utterback 1994b). At this stage innovation is likely to modify only minor aspects of the consolidated technology, and any changes introduced simply refine the dominant design (Clark, 1985). Authors propose several reasons for this change. Foster (1986) suggests that maturation is an innate feature of each technology: there is a threshold in performance improvement; once it has been reached, market and firm interest decreases and the advent of a new technological breakthrough is more likely. Consistently, Sahal (1981) indicates that there are limits to the improvement in technology performance, related to system complexity and scale. When these limits are reached, the only possible way to maintain the pace of progress is through radical system redefinition - that is, a move to a new technological platform. Utterback (1994b) and Adner and Levinthal (2002) add that as a market ages, evolution dynamics are mainly driven by production efficiency and cost reduction rather than technology performance, thus shifting the focus of innovation from product to process innovation. However, process innovation does not only have an impact on cost and scale. In some cases independent developments in processes related to the consolidated technology may create capabilities that open up new options and possibilities in the same or in new technological trajectories (Clark, 1985). Reinganum (1985) and Ghemawat (1991) propose that maturity occurs when there is less incentive for incumbent firms to innovate because of worries of obsolescence or replacement from a rival emerging technology.

While the generalizability of the above-mentioned stages across industries is widely recognized, the factors determining the advancement of the technological cycle can vary from an industry to the other. The next paragraph describes the factors generally affecting the technological evolution of an industry. The next chapter will discuss which of them are relevant to the specific case of environmental technologies.

3.4 Causal mechanisms in technological evolution

Although different streams of research highlight different drivers, there is a prevalent agreement on the fact that technological evolution in a certain industry is driven by the interplay between economic, technological, and socio-political factors (scientific advances, economic factors inside and outside companies, institutional variables, and unsolved difficulties on established technological paths). Figure 1 organizes the contributions of the different streams into a simplified classification of drivers of technological evolution. Accordingly, the interaction process that leads to the takeoff of the new technology is driven by three main factors: firm-level factors, environmental factors, and cognitive factors. Environmental factors can be further divided into institutional factors and market factors. Obviously the degree of complication of the interaction process depends on the industry: the more complex the product, the greater is the number of variables interacting in the evolutionary process, the longer is the time required to achieve dominance (Suarez, 2004).

Figure 1- Factors influencing technological evolution



3.4.1 Firm level factors

Technological evolution and the emergence of a dominant design can be accelerated by various factors related to the internal resources and capabilities of companies in the industry. It is important to notice that firm factors are strictly interrelated among each other, since they are all part of what has been defined by Cusumano, Mylonadis, and Rosenbloom (1992) as strategic maneuvering. These factors are particularly relevant for research and practice, since their inclusion in evolutionary models implies that a social system's decision of adopting an innovation can be influenced significantly by the management of that innovation.

Technology characteristics

Technological superiority. The extent to which the emerging technology is superior to the established one can accelerate the evolutionary process (Suarez, 2004). However, this relationship is not so straightforward, but it is rather conditioned by the attribute that determines technological superiority. The research on disruptive technologies postulates that in case in which technological superiority is associated to a disruptive/emerging attribute the process of market acceptance is more complex and requires more time (Christensen and Bower, 1996; Christensen, 1997).

Technological compatibility. Some industries are characterized by product complementarity, especially in markets characterized by high technological innovation. In these circumstances the penetration of a certain technology into the market is conditioned by the penetration of the complementary products as well, and the issue of technological compatibility becomes critical. When a firm develops a new technology following a logic of product compatibility it reduces barriers to adoption and accelerate the speed of market penetration of the new technology (Gatignon and Robertson, 1995).

Technological opportunism

Technological opportunism refers to the "sense–and-respond capability of firms with respect to new technologies" (Srinivasan, Lilien, and Rangaswamy, 2002, p.48), which conditions firms' decision to adopt a new technology. More specifically, firms will be able to adopt and foster the diffusion of a new technology if they develop at the same time technology-sensing capability – an organization's ability to acquire knowledge about and understand new technology development – and technology-response capability – an organization's willingness and ability to respond to the new technologies it senses in its environment. Technological opportunism facilitates company adoption of the new technology and, therefore, accelerates the evolution of the industry. In order to foster technological opportunism, the most relevant capability is the ability to reengineer business strategy to exploit the opportunities offered by the new market. In this direction, firm's complementary assets (manufacturing capabilities, market channels, brand image, etc.) have been largely recognized as drivers of successful technological innovation (Suarez and Utterback, 1995; Rogers, 1995; Teece, 1986; Tripsas, 1998). The more the new technology is related to the existing knowledge base and absorptive capacity of the firm, the higher the chances of adoption will be (Cohen and Levinthal, 1990). However, this relation is not so straightforward: according to the literature on disruptive innovation, it is the resource dependence of incumbents that make them unable to take advantage of the innovative potential of disruptive technologies (Christensen and Bower, 1996; Christensen, 1997). Incumbents are so concentrated on their largest and most profitable customers, that it is exceedingly difficult for them to allocate resources to initiatives that do not directly serve these customers. As a result, in Christensen's perspective technological evolution is accelerated by the technological opportunism of new players rather than incumbents.

Design

The relationship between product design and technological evolution has been introduced and developed by Clark (1985). According to his thought, the evolutionary process of an industry is driven by the sequence of design decisions taken by companies over time. The design decision is not only the definition of the form to give to products incorporating the new technology, but also – and more importantly – the identification of the form that better fits the context in which the technology is introduced. In different words, product design does not only take into account the technical features of the new technology, but also the way in which market demands perceive and uses the new technology. As a result, once a new technology has been introduced into the market, it's the interaction with the customers that defines the *hierarchy* of design decisions embodied in successive generations of a new technology. The example from the automotive industry proposed by the author is particularly illuminating: once the car has been introduced into the market at the beginning of the twentieth century, it has been the market to decide the hierarchy of design issues to be solved by companies (first the automobile engine and later the transmission system). Thus, in order to understand the evolutionary pattern of a technology and to be successful in the development of the same technology, companies should master not only the technical aspects but also the emerging requirements of customers.

Pricing

Pricing has always been recognized as a key determinant of market demand, but it becomes particularly influential in the case of new technologies, given the various ways in which pricing decision can affect industry dynamics. In fact the prevailing belief is that price is a key explanatory variable in determining the sales takeoff time: sales for technological innovations are initially low due to their relatively high prices. Then, as prices of these technologies decline, the new products based on them cross a threshold of affordability and sales dramatically take off (Agarwal and Bayus, 2002). According to the research on network effects in technological industries (Katz and Shapiro, 1985), an early aggressive pricing can facilitate the creation of a larger installed base, which in turn contributes to the reduction of adoption risk and to the increase of adoption profitability for customers.

Marketing strategy

Another firm factor affecting technological evolution is the way in which companies use their marketing and public relation to support their disruptive technology. Diffusion models have often taken into account marketing mix variables to demonstrate their effect on the process of adoption (Lilien, Rao, Kalish, 1981; Horsky and Simon, 1983; Horsky, 1990; Jain and Rao, 1990), suggesting that different marketing strategies can generate different diffusion patterns.

As an example, some researchers focused their attention on the effect of product *pre-announcements*, which can create positive expectations about a company's upcoming introductions while at the same time cause customer "hold-up" with respect to competitor products in the market (Farrell and Saloner, 1986). Preannouncing conveys information about a forthcoming product (Eliashberg and Robertson, 1988). In doing so it can facilitate the creation of an installed base by potentially reducing customers costs of changing from an existing product or technology to an emerging one, and by ameliorating information asymmetries between the firm and its customers. The reduction in switching costs is due to the consumer's ability to plan the migration to the new technology over a more extended time. The net effect is a potential increase in the speed of technological takeoff. According to Eliashberg and Robertson (1988), consumers respond faster to new product offerings that are preannounced because they can better anticipate a switching path to the new product, especially if switching costs are high. Additionally, they become aware of the new product earlier, they learn about the benefits of the new product faster, and they can start a long purchase decision process earlier.

Some researchers have addressed the role of distribution in the diffusion of new technologies (Jones and Mason, 1990; Jones and Ritz, 1991; Gatignon and Anderson, 1998). The relevance gained by the distribution issue is due to the fact that the power of channels of distribution is increasing in many industries and retail concentration becomes more prevalent. Jones and Ritz (1991), for example, recognize that the adoption of an innovation by consumers is conditional on the innovation being distributed by the channels of distribution. The penetration of new technologies in the channel of distribution is therefore critical to the acceleration of the diffusion rate and to the emergence of a dominant design. Distributors carry the technological innovation if there is indication of potential (Jones and Mason, 1990). This depends on the other marketing activities implemented by the firms but also on the consumer response, as can be observed from early distribution.

Advertising is another way in which companies can definitely influence the technological evolution of an industry. When decoding information about a new technology, consumers develop taxonomies based on similarities with existing products in order to categorize novel products (Gregan-Paxton and John, 1997). By using advertising messages to influence what analogies are formed, producers can shape the performance criteria applied in the new domain (Moreau, Markman, and Lehmann, 2001).

Installed base

According to research in industrial economics, in presence of network effects a firm (or a group of firms) with a large installed base of users will be more successful in the introduction of a new technology and more effective in accelerating the takeoff of products incorporating the new technology (Katz and Shapiro, 1985). It is important to notice that the installed based of a technology acts as an accelerator of the technological evolution and always in coordination with firms' strategy. In other words, it represents an "extra push" to the chances of technological dominance, in addition to other more direct strategic actions (marketing, technological superiority, etc.) and external forces (Suarez, 2004).

3.4.2 Environmental Factors: Institutional Forces

The institutional perspective has contributed to the introduction of the notion that technological development is a co-evolutionary phenomenon, driven by a continuous and reciprocal interaction between technology and its environment (Rosnekopf and Tushman, 1993; Van de Ven and Garud, 1993). According to this viewpoint, a set of environmental forces interacts with the supply side drivers of technological diffusion across time, thus shaping the life cycle of the new technology. Consequently, the decision to adopt a new technology is driven not only by an individual assessment of the innovation's performance, but also by the pressures of a number of external actors involved in the takeoff of the new technology. The next paragraphs will describe these forces in detail.

Government regulation

The role of regulations is particularly relevant in the early stages of the introduction of a new technology. Given the general weakness of market mechanisms when uncertainty is high, the role of bridging institutions can facilitate the selection of a certain technological solution (Dosi, 1982).

Government regulation can speed the emergence of a new technology through compelling the adoption of a standard (Anderson and Tushman, 1990; Suarez, 2004).

However, the role of government in the takeoff of a disruptive technology is not limited to regulation: for example, government purchases of a product incorporating the new technology in the early stages may signal a general approval of the new technology and stimulate the adoption by other segments in the market (Suarez, 2004).

Media

Another institutional factor sometimes considered in explaining the technological evolution of an industry is the media-provided information on the new technology. Institutional theorists claim that, through framing and exposure, infomediaries legitimate firms and technologies by influencing stakeholder perceptions of the desirability and appropriateness of the characteristics and performance of the new technology (Elsbach, 1994; Lamertz and Baum, 1998; Zuckerman, 1999). Media coverage can play its legitimization role in two ways: it can reflect public evaluation and therefore provide a measure of technology legitimacy (Baum and Powell, 1995; Elsbach, 1994); alternatively, it can affect perception of legitimacy and, thus, becoming an active force that firms need to manage strategically to pursue technology legitimacy (Hoffman and Ocasio, 2001).

3.4.3 Environmental Factors: Market Pressures

Market pressures are generally characterized by a limited strength when compared with the other forces acting on the technological evolution of a certain industry. Changes in market conditions (demand patterns, distribution structure and shares, production costs, etc.) are very relevant to companies, but their effect tends to be limited to advancement on the existing technological trajectory. The main argument here is the rejection of a "pure" market-pull theory of radical technological change: companies are not passive to the technological change requested by the market; companies are not able to forecast ex ante which technological paradigm (and, consequently, trajectory) will be preferred by the market; companies' creative capability may not fit with changing market conditions (Dosi, 1982).

Demand dynamics

The role of demand in the technological evolution of an industry has received extended attention. In the research on the economics of innovation, there are various empirical and theoretical strands that discuss demand-related dynamics, from the old debate "demand pull vs technology push" (Schmookler, 1966; Meyers and Marquis, 1969), to the analysis of demand, market structure and innovation (Kamien and Schwartz, 1975; Sutton, 1991, 1998). Demand has also been related to the emergence of disruptive technologies. In this literature, the slower takeoff of disruptive technologies is explained by the fact that they originally serve niche segments of the market, which are the only ones valuing higher the disruptive performance attributes. Further developments in the performance of both the disruptive and mainstream attributes lead these technologies to a level sufficient to attract mainstream customers (Christensen and Rosenbloom, 1995; Christensen, 1997).

Also the whole vast literature on diffusion inspired by Roger's work can be regarded as an attempt to understand the relationship between demand and innovation. For example, trialability, complexity and observability of products incorporating new technologies are characteristics that refer directly to the level of uncertainty faced by a potential adopter.

Contrary to all these research developments in the realm of demand and innovation, however, the inclusion of demand in the analysis of the relationship between industrial dynamics and innovation is still in its infancy. There are many questions that did not find a clear and unique answer yet: in which ways and forms does demand affect innovation and the dynamics of industries? Can demand be distinguished only in terms of its inertia and receptivity to new technologies? And (related to the previous question) is demand only a passive recipient of new products, or does it actively contribute to develop and generate new technologies? And which dynamic processes are triggered by demand during the evolution of an industry?

Answers to these questions may start from the identification of the various dimensions of demand that affect industrial dynamics and innovation.

Two key aspects of demand that are relevant for innovation in industries are consumer behaviour and consumer capabilities. Consumer behaviour plays a major role in affecting innovation. It includes the presence of information asymmetries and imperfect information with respect to new products and technologies as well as routines, inertia and habits concerning existing products and technologies. Also consumer capabilities influence technological change in an industry: as an example one could only mention the role of absorptive capabilities and their distribution among consumers and users. The focus on the behaviour and capabilities of consumers and users opens the way for a very productive analysis of how demand affects innovation and the specific patterns of industrial dynamics.

Network effects

In the industries in which they are present, network effects play an important role in technology adoption. Network effects exist when the utility derived by a consumer adopting a new technology is positively related to the total number of consumers owning the same technology or belonging to the same technological network (Katz and Shapiro, 1985, 1986). Network effects are direct when the utility of a product to each user depends on the number of other users (e.g. fax machine, telephone). Network effects are indirect when the link between individual utility and the number of users depends on the increased availability of complementary products (e.g. movies in DVD for DVD players, video games for video game consoles). As to the direction of network effects on technological adoption, some studies suggest that they accelerate the emergence of a new dominant design: in industries characterized by high levels of network effects, potential adopters tend to anticipate the adoption of the new technology and the dominant design emerges quickly; this accelerates further adoption and consolidates the supremacy of the dominant design (Schilling, 2002; Shapiro and Varian, 1999). On the other side, the 'lock-in' effect suggests that strong network effects may prevent customers to abandon previous technologies. In fact prospective customers may adopt a 'wait-and-see' attitude, resulting in excess inertia, which slows down the emergence of a dominant design (Farrell and Saloner, 1986; Srinivasan, Lilien, and Rangaswamy, 2006).

Characteristics of the technological field

The structure and the dynamics of the particular technological field are also significantly relevant in explaining the takeoff of a new technology (Suarez, 2004). Aspects like the number and the relative power of the actors, the level of cooperation versus competition, the market penetration, the characteristics of the research community, the industry's value net, can clearly condition the evolutionary process.

The role of the value net has received particular attention by the literature. The value net refers to the set of suppliers and producers of complementary products that contribute to the delivery of value to the customers. The higher the interdependences within the value net, the higher the incentive for each firm to support the new technology, and the easier the takeoff of products incorporating the new technology (Amit and Zott, 2001; Srinivasan, Lilien, and Rangaswamy, 2006; Tushman and Rosenkopf, 1992; Wade, 1995)

For example, in the software developer community there is significant support for open standards, which deeply condition the technological trajectory in the industry.

3.4.4 Cognitive aspects of technological evolution

The causal mechanisms discussed in the previous paragraph are based on the research finding of the economics (Dosi, 1985; Nelson and Winter, 1982; Sahal, 1981) and organizational (Tushman and Anderson, 1986; Tushman and Rosenkopf, 1992; Utterback, 1974) perspectives on technological evolution.

An emerging stream of research argues that cognitive factors should be considered in order to get a thorough understanding of the technological life cycle (Kaplan and Tripsas, 2008). According to these researchers, the interaction of the cognitive technological frames of multiple actors shapes the evolution of technology (Acha, 2004; Kaplan and Tripsas, 2008; Orlikowski and Gash, 1994). Technological frames refer to the way in which actors (companies, customers, institutions) conceptualizes and understands a technology. Specifically, technological frames determine the way in which actors classify a new technology relative to existing technologies and which performance criteria they use to assess the technology.

A technological frame requires the definition of beliefs, artefacts, and evaluation routines of a certain technology (Garud and Rappa, 1994). Defining the beliefs associated to a certain technology means outlining the knowledge base of a technology and what individuals believe is possible. These beliefs can include the "rules of thumb" (Sahal, 1981b), the "search heuristics" (Nelson and Winter, 1982), and the cause-effect relationships (Garud and Rappa, 1994) that researchers use to address technological problems. As to the technological artefacts, they consist of the form and functional characteristics of a technology (Sahal, 1981b). Form characteristics include attributes such as dimensional shape and material of construction. Functional characteristics refer to how the technology is used. Finally, the evaluation routines associated to a technology indicate the way in which the performance of the technology is assessed (Kaplan and Tripsas, 2008).

Different technological frames in terms of beliefs, artefacts and evaluation routines explain the difficulties in introducing technological discontinuities in a market; competing technological frames are a source of variation in the introduction stage of technological life cycles; framing activities help drive the interaction among different actors in the achievement of a dominant design; and, finally, the intertwining of technological frames and organizational architecture in the maturity stage contribute to explaining why transitions are so problematical.

3.5 Research Gaps

Although technological evolution has captured the interest of many researchers in various disciplines, research gaps still remain. They refer to the lack of a comprehensive framework explaining the evolutionary path of new technology, and, more importantly, the scarcity of studies approaching the issue from an empirical perspective.

As to the first point, the literature discussed in the previous chapter tended to focus on the role of one (or some) of the actors capable of affecting the evolutionary pattern of a new technology. Most of the research has focused primarily on the role of producers' actions in shaping the direction of a technology trajectory (e.g., Utterback, 1994). Even Garud and Rappa (1994), who explicitly examine the effect of researcher beliefs on technical artefacts, focus mainly on producer organizations. When users are recognized as an important factor in the literature, they are typically portrayed as making an exogenous, passive choice about whether or not to adopt the new technology (Rogers, 1995). Only in rare instances are users given a more active and purposeful role in shaping technological outcomes (Tripsas, 2008; von Hippel, 1986). Even less has been done to understand their interaction with producers. The one important exception is Clark's (1985) analysis of the development of design hierarchies, which suggests that producer and user interactions inform the paths that technology development takes, but this aspect of Clark's work has not been picked up in subsequent scholarship. Where the role of institutional actors (such as government agencies, the media, user groups, standards bodies, industry associations and other like groups) in influencing technology evolution has been discussed (Garud and Rappa, 1994; Rosenkopf and Tushman, 1998; Van de Ven and Garud, 1993), the focus has been on the legitimizing role that institutions play in providing "an industrial system that embodies the social, economic, and political infrastructure that any technical community needs" (Van de Ven and Garud, 1993, p. 2). In reality, theoretical contribution broadly claimed the more active role that institutions can take in, for instance, explicitly endorsing a particular technology through regulatory action. Additionally, most of the effort has been devoted to the identification of the different factors that affect the final outcome of a technology battle - technological superiority, firm resources, institutions' role (Suarez and Utterback, 1995; Schilling, 1998; Shapiro and Varian, 1999; Scott, 1994). Insufficient insight has been provided on how these factors play out in different situations, and particularly how their effect varies over time. A few studies provide in-depth insights into the process by which technology achieves dominance, but these have been typically based on one or a few case histories (Khazam and Mowery, 1994; Garud, Jain, and Kamaraswamy, 2002; Gawer and Cusumano, 2002), and it is therefore hard to generalize from their results.

The present research attempts to contribute to both the research gaps previously identified. Specifically, the framework that will be presented in the next chapter explains the evolution and takeoff of environmental technologies by considering the actions technological frames of producers, users and institutions, and their interactions with each other. Additionally, the empirical context of the research allows a certain degree of generalization to the particular industries included in the data collection, and perhaps to all the industries in which environmental technologies are involved.

Chapter Four

Theory Building and Hypothesis Development

4.1 Introduction

As illustrated in the general introduction, the aim of this research is to explain the diffusion problems of environmental technologies through the lens of technological evolution (Anderson and Tushman, 1990; Clark, 1985; Dosi, 1982; Schilling, 1998; Suarez, 2004; Suarez and Utterback, 1995; Utterback and Abernathy, 1975; Utterback and Suarez, 1993). According to this literature technological change can be fruitfully characterized as a socio-cultural evolutionary process of variation, selection and retention through which a dominant technology finally emerges (Anderson and Tushman, 1990). This process of selection is shaped by social, political, and organizational dynamics acting both at industry and firm level. Being green technologies disruptive innovations in each industry in which they are implemented, their full acceptance is subordinated to the repeated interaction of firm capabilities, managerial willingness, institutional rules and competitive dynamics.

Understanding the role of these factors in the various stages of the diffusion process is fundamental to comprehend the peculiarities of environmental innovations and of the industries in which they are implemented. The present work attempts to accomplish this objective through the analysis of the time to takeoff needed by a new product incorporating environmental technologies, and through the identification of systematic patterns in the impact of evolutionary forces. The time to takeoff will be analyzed following the graphical and estimation procedures normally adopted in marketing research (Golder and Tellis, 1997; Stremersch and Tellis, 2004; Stremersch et al., 2007; Tellis, Stremersch, and Yin, 2003). The effect of the evolutionary forces will be studied through the development of an evolutionary framework and its empirical test over time.

In this way, the research intends to contribute to both the research field of technological evolution and the literature on corporate environmental management (CEM). As to the technological evolution field, this work affects prevalently the technology management literature with the following contributions:

- It proposes a comprehensive framework of the factors that play a role in technological evolution process, while different streams of literature have tended to emphasize subsets. Technology management literature has approached the technology evolution process from a strictly technological perspective (Anderson and Tushman, 1990; Christensen, 1997; Clark, 1985; Dosi, 1982; Sood and Tellis, 2005; Utterback and Abernathy, 1975), from an institutional perspective (Garud et al., 2002; Tushman and Rosenkopf, 1992), from a cognitive perspective (Garup and Rappa, 1999; Tripsas and Gavetti, 2000), and from a network economics perspective (Katz and Shapiro, 1985). However, there are still few integrative models (Schilling, 1998; Srinivasan et al., 2006; Suarez, 2004) that combine the findings of different perspectives in order to get a thorough understanding of the process. The evolutionary framework discussed in this research combines external and internal factors that drive technology adoption, thus blending together inputs from the technological, institutional, and cognitive domain.

- The study empirically tests the comprehensive framework over time. Up to now research has mainly concentrated on the identification of the various factors affecting technology diffusion. Little attention has been given to how these factors actually play out in different empirical situations and how their impact changes over time (Suarez, 2004). Few studies provide empirical evidence on the process by which a technology achieves a dominant position in an industry, but these have typically been based on case studies (Khazam and Mowery, 1994; Garud et al., 2002; Gawer and Cusumano, 2002) or they did not take into account the time dimension (Srinivasan et al., 2006). Through the collection of secondary data, the present research empirically tests a set of hypotheses on the importance of different factors in different stages of the diffusion process.
- The study contributes on the debate on the appropriateness of the S-shaped curve as a graphical representation of the diffusion pattern of new technologies. There is extensive agreement on the fact that technologies evolve through an initial period of slow growth, followed by a fast acceleration, and culminate in a plateau. However empirical support for the S-shaped pattern is scant (Foster, 1986; Utterback, 1994), and recent studies

have generated results that contradict the prediction of a single S-curve (Sood and Tellis, 2005; Stremersch et al., 2007). The takeoff analysis implemented in this research adds to this debate with some insights on an unexplored type of technology.

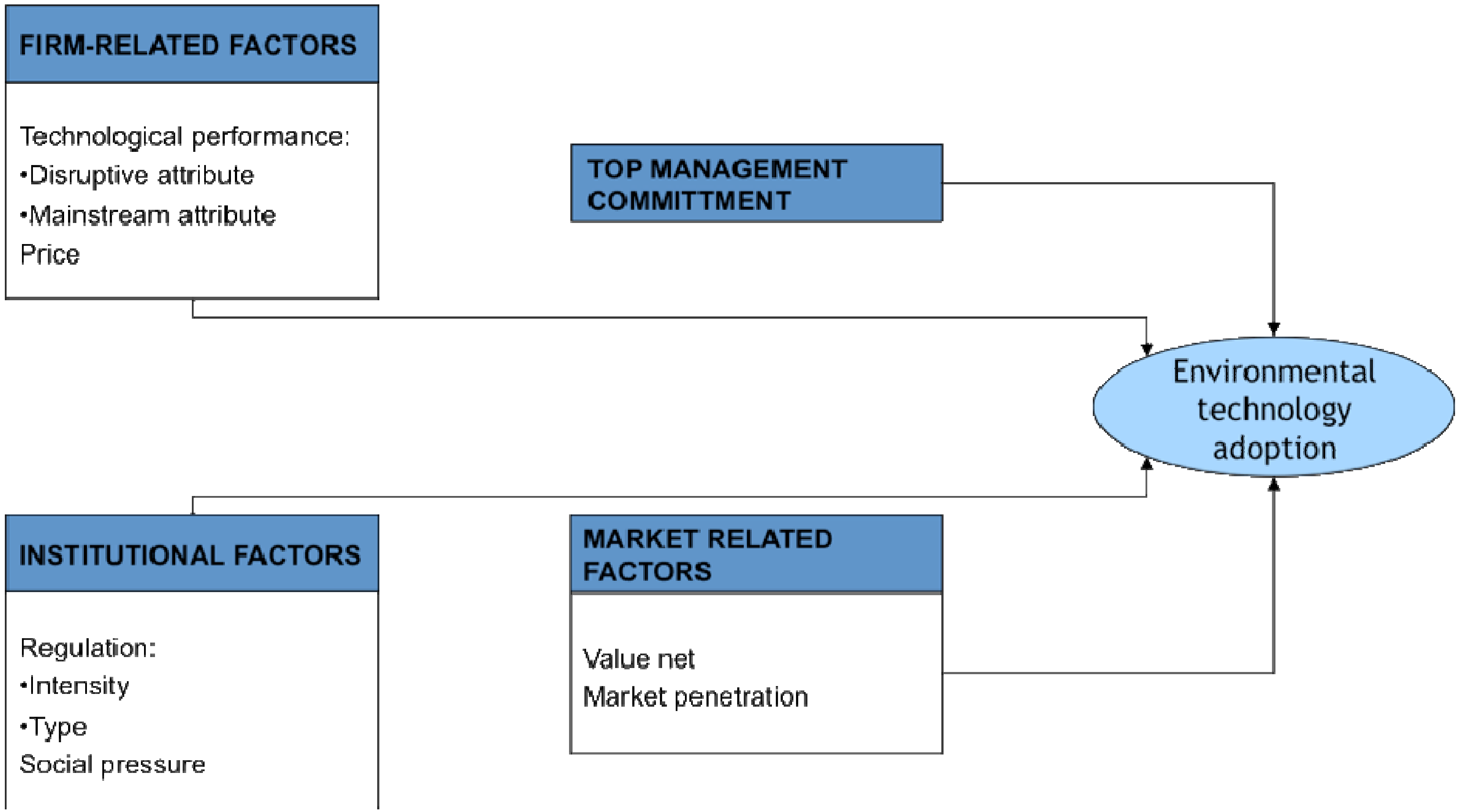
With regard to the literature on corporate environmental management, the present research generates the following contributions:

- The study integrates resource-based and institutional arguments to identify the factors relevant in explaining firm's commitment to environmental management and the penetration of environmental technologies. Most studies of the factors that influence environmental commitment have taken either a resource-based orientation (Hart, 1995; Klassen and Whybark, 1999; Russo and Fouts, 1997) or an institutional orientation (Hoffman and Ventresca, 1999, 2002; Jennings and Zandbergen, 1995). Few have integrated the two approaches (Banajaree et al., 2003; Bansal, 2005), and none has focused on environmental technologies as the outcome of environmental commitment. Approaching the environmental issue from a technological perspective is new, it provides theoretical justification to the combination of factors of different nature, and it shifts the focus on an important variable like the market performance of the environmental technology.
- The study approaches the environmental issue from an industry perspective and, thus, adopts a different and more effective indicator of environmental performance, namely the market adoption of environmental technologies. The research on environmental management has been characterized by a general scarcity of useful data, especially with reference to environmental performance. Up to now the most used proxy for environmental performance

is the amount of wastes a company generates (Sharma and Henriques, 2005) and the U.S. TRI program has been the most widely used source of quantitative data for environmental research (Dooley and Fryxell, 1999; Kassinis and Vafeas, 2006; King and Lenox, 2000, 2002; King, Lenox, and Terlaak, 2005; Klassen and Whybark, 1999; Russo and Harrison, 2006). While the distinct advantage of this data set is its accuracy and its focus on tangible impacts on the natural environment, it (and others like it) provides only a limited perspective on an organization's environmental performance. Specifically, it accounts only for manufacturing processes rather than the entire life cycle of the product, and it entirely ignores the impact of external factors like regulations or demand dynamics. The lack of rich databases leads many researchers to employ surveys and case studies for studying environmental performance, with all the limitations that those methods entail, especially in a 'sensitive' area like the natural environment. The use of data on sales of products incorporating environmental technologies can be a convincing option for measuring environmental performance.

The following paragraphs will illustrate a holistic model of technological evolution, which captures the internal and external factors affecting the takeoff of environmental technologies. The theoretical model is depicted in Figure 2. First, a theoretical justification of the variable selected will be provided. Then, drawing on theory and empirical research on technological evolution and environmental management, the research hypotheses will be developed.

Figure 2 - An evolutionary framework for the adoption of environmental technologies



4.2 A co-evolutionary approach to the emergence of trajectories in green technologies

Environmental management decisions are a reaction to both institutional and technical pressures, which co-exist and even co-construct each other. Several researchers have called for a greater integration of the decision process of individuals, institutions and business firms in the context of both technological change and environmental management. Some authors have started exploring this research line, by paying attention to the differential effects of both technical and institutional factors in the diffusion of corporate environmentalism (Bansal, 2005, Hoffman, 1999; Jennings and Zandbergen, 1995). On one side these papers correctly emphasize the importance of looking at organizations within more complex environments and question the long-standing assumption that institutional and technical forces conflict with one another. However, these papers still frame the technical and institutional environments as separate from one another, while the reality is characterized by a continuous interaction between institutions and competitive environment in shaping industry characteristics and dynamics.

The cyclical model of technological change (Anderson and Tushman, 1990) considers both social and organizational factors and can be effectively used to describe the evolutionary dynamics in the takeoff of environmental technologies. Accordingly, technological change can be characterized as a socio-cultural evolutionary process of variation, selection, and retention. Variation is generated by periodical technological breakthroughs. Selection and retention are driven by social, political, and organizational dynamics whose outcome is the affirmation of a technology as dominant in an industry.

Environmental technologies can be regarded as the breakthrough innovations that trigger eras of ferment in the industries in which they are introduced. Consistently with the definition of disruptive technology (Christensen, 1997), environmental technologies underperform dominant technologies along the dimensions traditionally valued by mainstream customers. At the same time they offer superior performance in rising features at the moment only prized by a reduced fringe of customers (environmental conscious customers). Taking hybrid vehicles as an example, at the moment of their introduction at the end of the 90s, they did not satisfy the basic performance requirements of the general market (speed, acceleration, cruising range). Their sales were limited, given the small size of the market segment that considers gas emissions and fuel effectiveness as main expected benefit in a car. However, the progressive improvement in the mainstream performance attributes accelerated the market penetration of hybrid cars, and the interaction with social, cultural, and political factors has bolstered the takeoff of the technology.

In order to illustrate and empirically test the evolutionary pattern, this study proposes a "hybrid" framework, whose relationships have been built on the basis of institutional, competitive advantage, and cognitive.

In an attempt to coordinate the findings of the two fields, the present research suggests that the nature and the level of environmental technology adoption in a certain industry is driven by industry isomorphism, which can be regarded as the convergence of a focal company's environmental practices to those of other corporations within its organizational field. Obviously this convergence is driven by the coordinated action of institutionalized pressures.

However, the institutional pressures are not strong enough to tilt the balance in favour of the environmental technologies if they are not coordinated with firm-level variables, which are the variables that managers can influence more directly and that can generate sustainable competitive advantage for the firm.

Although they have been added only recently into technological evolution debate, cognitive factors are particularly relevant in the case of new environmental technologies, since one of the main impediments to their real takeoff is the deeply divergent technological frame they introduce into the market. Looking at the definition of technological frame, the ethical component of environmental technologies represents a point of departure from the mainstream technologies in each industry in which they are introduced: given the relative novelty of ethical technological innovation, it is cognitively difficult to categorize them with respect to other technologies. Additionally, the performance criterion to evaluate environmental technologies is strictly ethical and no longer only related to tangible indicators. In fact the main benefit provided by ethical technologies like environmental technologies is intangible, long-term, and collectively shared in its nature: when a customer buys a traditional car his main benefit will be the immediate availability of a means of transport with his favourite level of speed and power; when a customer buys a hybrid car his main benefit will be a better air quality for people coming.

Consequently, the acceptance of environmental technologies is subordinate to a deep change of the technological frame for both consumers and companies (top management and, progressively, employees). Consumers have to get used not to be driven by individualism and short-term orientation in their technology assessment and purchase behaviour. Companies have to adopt a long-term perspective in assessing environmental technologies, and target their marketing activities to consumers who are not short-term oriented anymore.

Since this change affects the foundations of industry technological frame, the transition is very difficult, time- and resource- consuming, and uncertain in its ending. The coordination with institutions becomes critical.

4.3 Timing of different factors

Institutional pressures are likely to have a prominent role in the early stages of the introduction of environmental technologies (Bansal, 2005; Hoffman, 1999; Richards and Gladwin, 1999). Early years are characterized by higher degrees of ambiguity and uncertainty on the performance of the new (environmental) technology and on its potential of replacing its predecessor. Coercive pressures (by the government or the media) can help in reducing this initial uncertainty.

The opportunity of generating sustainable competitive advantage from environmental technologies could be another driver of the early corporate commitment (Bansal, 2005). Certain companies can embrace CEM and environmental technologies at the early stages of their development in order to profit from first mover advantages. Generally, these companies are characterized by certain cultural values and by the necessary organizational slack to appreciate the full innovative potential of environmental technologies. As environmental technologies become progressively institutionalised, competitive advantage opportunities become clearer and more appealing.

4.4 Research hypotheses

In the following paragraph the relationships introduced by the theoretical framework in Figure 1 are developed into testable hypotheses. To select the most relevant factors the theoretical insights have been combined with some initial interviews with key informant.

4.4.1 The takeoff of environmental technologies: the shape of technological progress

Knowing the shape of technological progress is important in order to identify the key moments in technology life cycle and, consequently, adopt the most appropriate strategic and marketing actions.

Initially, sales of a new technology are generally flat. After some time, a critical mass of adopters may emerge and the sales show a distinctive takeoff. The takeoff of a technology is the point of transition from the introduction to the growth stage of the life cycle. It is the first remarkable and sustained increase in the sales of the product category incorporating the new technology. After the takeoff additional consumers adopt the new technology until the market is saturated and sales begin to decline.

Although the literature suggests that the above-described technological evolution process follows an S-curve, the supporting empirical evidence is limited (Foster, 1986; Utterback, 1994) and there is no specification of the characteristics of the S-curve, like the slope, the duration of the stages, or the timing or steepness of the turning points. Recent studies (Sood and Tellis, 2005; Stremersch et al., 2007) have shown that accepting the notion of S-shaped curve for technological innovation might be risky, since many technologies did not exhibit an S-shaped pattern and several others displayed multiple S-curves, suggesting that a technology can experience an additional growth after a period of slow or low improvement. The implications of these findings are significant, as they suggest that abandoning a technology because of a slowdown in its growth can be a premature decision.

The empirical context of this research adds another element to the discussion: the fact that the technologies analyzed in this project are superior in terms of an "ethical" attribute suggests that the diffusion could follow a pattern that is different from other technologies (i.e. high-tech). The objective of the present research is to determine whether it is possible to identify any pattern or generalization about the S-curve parameters in the case of environmental technologies (and in the more general case of ethical technologies). In terms of a testable hypothesis regarding shape, the most precise hypothesis that can be formulated is the following:

Hypothesis 1: Technological progress on the environmental dimension follows a single S-shaped growth curve.

4.4.2 Technological performance and product design

Performance is definitely a main determinant of the takeoff of any type of technology. In the case of environmental technologies, consistently with their characterization as disruptive, the takeoff will depend on the performance of both the disruptive attribute (environmental friendliness) and the mainstream attribute.

For producers of environmental products, the inclusion of environmental technologies as an integral part of the design process represents one of the most demanding tasks. Environmental technologies can be incorporated through various design decisions, going from the rethinking of the entire product to less visible changes such as material selection, package design, and energy and solvent usage. However, the biggest challenge to each company is to develop environmentally friendly technologies that do not significantly conflict with traditional product attributes or performances, such as speed, durability, or convenience. In fact, given the disruptive nature of environmental technologies, very often the improvement of one attribute can only be accomplished at the expense of another.

In the general case, the following dynamics in the evolution of competing technologies take place (Christensen, 1997). Sometimes in the life of an old technology, a new technology enters the market basing its superiority on a new attribute. At the beginning, the new technology makes slow progress because its performance in the mainstream attribute is inferior to the established technology, and its superior performance in the disruptive attribute is not valued by the market yet. However, at some point, the new technology grows rapidly and improves in both the mainstream and disruptive attribute. In contrast, the old technology improves at a much slower rate, even though major investments are made to further develop the old technology. As a result a point is reached when the new technology crosses the old technology in overall performance, thus accelerating the exit of the old technology from the market.

In the case of environmental technologies, the disruptive attribute has an ethical nature, thus representing an unexplored situation in the research on technological evolution. Specifically, the disruptive attribute provides a collective and long-term benefit to the consumer, while the type of benefit generally offered by non-environmental technologies is individualistic and short-term. Given the lack of studies comparing the evolution pattern of environmental and non-environmental technologies, there is no evidence of how this difference impacts the market performance of environmental technologies. On the basis of empirical observation and anecdotal evidence, it could be hypothesised that the mainstream attribute remains influential in consumer purchase decision for a longer period of time than in the general case. In fact, even if the consumers develop a certain degree of environmental sensitivity, they do not turn their buying intention into effective purchase if the environmental products do not reach and maintain a minimum threshold in the mainstream performance attribute. As a result, both the mainstream and the environmental (disruptive) attribute of technological performance should maintain their impact on the takeoff of the environmental technology during the entire diffusion process. While the impact of the performance of the disruptive attribute follows a similar pattern in both environmental and non-environmental technologies (increasingly positive), the impact of the mainstream attribute is different. Specifically, in the general case, the performance in the mainstream attribute has a negative decreasing effect on the penetration of the new technology. In the case of environmental technologies, this effect should be positive and constant over time. Given the scope of this research, only the second relationship will be empirically tested.

Hypotheses 2a: The performance of the environmental (disruptive) attribute positively affects the adoption (take-off) of environmental technologies.

Hypotheses 2b: The performance of the mainstream attribute positively affects the adoption (take-off) of environmental technologies.

4.4.3 Price

Several studies have identified price as the single most important factor determining the takeoff of new technologies (Russel, 1980; Foster, 1986; Golder and Tellis, 1997). Theoretical research concludes that optimal prices are decreasing when the new technologies takeoff in the market and the supply curve shifts outwards (Bass, 1980; Klepper, 1996). Empirical studies supporting this conclusion include Golder and Tellis (1997), who find that new consumer durables with low relative prices have a quick sales takeoff time, and Argawal (1998), who reports declining price trends for most new consumer and industrial product.

The logic behind these findings is that, at the moment of their introduction, new technologies are characterized by basic technological feasibility and relatively high prices. The high price hinders immediate wide market acceptance (Golder and Tellis, 1997), especially in the case of environmental technologies whose added benefit is not immediately experienced by the consumers. However, the prices of new products drop steadily especially in the first few years and, at some point, the new product crosses a critical threshold of affordability. At that point, sales take off dramatically. The faster the price decreases, the sooner the sales takeoff.

Hypothesis 3: The price of products incorporating environmental technologies negatively affects the adoption (take-off) of environmental technologies.

4.4.4 Regulatory pressure: intensity and type

Regulatory pressure is particularly effective in accelerating the penetration of a new technology, especially when the intervention directly mandates the use of a certain technology (Suarez, 2004). In situations characterized by high degrees of technological uncertainty (like in the case of environmental technologies), regulatory pressure could be determinant in the takeoff.

The effectiveness of regulatory forces is related not only to the fact that they are often coercive, but also to the institutional mechanism of legitimacy connected to them. Accordingly, regulatory forces provide its organizational subjects with legitimacy through the recognition of the organization's existence by the regulatory jurisdiction, and in this manner allowing the firm to function and operate (Deephouse, 1996). Oliver

(1991) suggested that high degree of legitimacy, potential economic gains from conformity to regulatory pressure, and a high level of legal coercion increase the chances that firms act in line with such pressure. Consequently, given the assumption that environmental strategies are a source of legitimacy and provide economic returns, greater strength of regulatory forces should inspire more environmental commitment and, consequently, faster penetration of environmental technologies into the market. This should hold in the case of both supply-oriented and demand-oriented environmental regulatory actions. While in the case of demand-oriented intervention the link with takeoff (sales of the new technologies) is clear, in the case of supply-oriented regulation companies will push the environmental technologies in the market in order to profit from the extra costs required by the compliance to regulation (future stages of the research will be devoted to empirically verify this assumption).

Several empirical studies on the relationship between environmental policy and technological innovation have been undertaken. Lanjouw and Mody (1996) examined the relationship between the number of patents granted and the environmental policy strength, measured in terms of pollution abatement expenditures at the macroeconomic level for Japan, US and Germany. They found that pollution abatement cost affects the number of patents successfully granted with a one- to two-year lag.

Using US industry-level data, Jaffe and Palmer (1997) extended Lanjouw and Mody's study and confirmed that environmental regulation increases R&D expenditures. They also stressed the necessity to examine the hypothesis on the relative strength of the effects of flexible versus prescriptive environmental policy regulation on environmental innovation.

Brunnermeier and Cohen (2003) used US manufacturing industry data and empirically analyzed factors that determined environmental technological innovation. They paid close attention to the fact that emission reduction pressures come not only from domestic regulatory authorities, but also from the international regulatory and market environment. They found that environmental innovation becomes more active as pollution abatement expenditure increases.

Considering the previous studies and the authors' understanding of industry dynamics, the following hypothesis can be formulated:

Hypotheses 4: Regulatory forces positively affect the adoption (take-off) of environmental technologies.

Although the empirical evidence is still limited, the literature on environmental commitment advises that different types of governmental intervention can have different impact on corporate environmental strategies and, as a result, on the market takeoff of green products. According to the literature, two main distinctions can be made: (1) market-based environmental policies versus direct policies; (2) measures oriented towards changes in production processes (CPP) versus measures oriented towards end-of-pipe abatement.

The distinction between market-based and direct policies is in the fact that in the former there is a market incentive in the environmental policy (emission trading programs) while in the latter there is simply a direct obligation to comply (taxes on emissions). Market-based measures are intrinsically better since there is always an incentive to reduce pollution (more credits to sell in the market for pollution rights), whereas with direct regulation, a polluting company has no incentive to pollute any less than what is allowable.

Some studies supported this assumption. Kerr and Newell (2003) studied environmental regulations related to lead concentration contained in gasoline in the US. It was found that the introduction of a tradable permit system promotes the adoption of new technology, and that generally policies using market incentives stimulate new technology in a more significant manner than policies that do not provide market incentives. Jaffe and Stavins (1995) examined the role of different policy measures on technology diffusion. Looking at building insulation practices, they found that subsidies for energy conservation have a stronger influence than energy taxes, and that direct regulations (such as building codes) had little. Popp (2003) examined the effects of the introduction of the tradable permit system for SO_2 emissions as part of American Clean Air Act amendments on the technological efficiency of desulphurization. Comparing the removal efficiency of desulphurization before and after the introduction of the emission trading system, he finds that the emission-trading program induced innovation. Accordingly, the following hypothesis is formulated:

Hypothesis 5a: Market-based incentives have a stronger impact on the adoption (takeoff) of environmental technologies than direct policies.

The distinction between measures oriented towards changes in production processes (CPP) and measures oriented towards end-of-pipe abatement implies that the first typology is preferable because it stimulates process and product innovation and can become an indirect source of competitive advantage. In fact end-of-pipe technologies are not an essential part of the production process, but are add-on measures so as to comply with environmental regulation. Incineration plants (waste disposal), wastewater treatment plants (water protection), sound absorbers (noise abatement), and exhaust-gas cleaning equipment (air quality control) are typical examples of end-of-pipe technologies. In contrast, cleaner production technologies are seen as directly reducing environmentally harmful impacts through changes within the production process. The recirculation of materials, the use of environmentally friendly materials (for example, replacing organic solvents by water), and the modification of the combustion chamber design (process-integrated systems) are examples of cleaner production technologies. Empirical evidence on this issue is rare due to a lack of technology-specific firm data. By analyzing the effects of a German environmental investment program, Horbach (2004) shows that in some cases process-integrated measures, as opposed to end-of-pipe technologies, lead to significant cost savings. The same results are obtained in a series of case studies carried out by Hitchens et al. (2003) for European SMEs. Furthermore, Walz (1999) shows that the introduction of new, integrated technologies in order to curb CO_2 emissions may lead to an increase in total factor productivity.

Accordingly, the following hypothesis is formulated:

Hypothesis 5b: measures oriented towards changes in production processes have a stronger impact on the adoption (takeoff) of environmental technologies than measures oriented towards end-of-pipe abatement.

4.4.5 Media pressure

Empirical studies have proved that the media has been significantly influential on corporate environmental commitment as the main expression of public concern (Bansal and Clelland, 2004; Bansal and Roth, 2000; Bowen, 2000; Henriques and Sadorsky, 1996). In this way, media acts as an institution-building force, shaping the norms of acceptable and legitimate environmental practices. Media coverage can affect the diffusion of environmental technologies through the exposure and framing of information. Exposure refers to the amount of media coverage received by the emerging environmental technology and by the sponsoring firms. Research has identified several mechanisms through which exposure leads to favourable impressions about firms and technologies. These mechanisms can be easily extended to the case of environmental technologies. Repeated exposure to a technology (or to a product incorporating that technology) generates familiarity and, possibly, interest to it (Harrison, 1977; Zajonic, 1968). For an extended period of time, information about the characteristics and performance of environmental technologies has been very limited and contradictory, thus negatively influencing the willingness to adopt products based on them. Higher and reliable media coverage can contribute to reduce the uncertainty on performance and the perceived risk of adoption that have prevented many people to switch to environmental technologies. Additionally, the repetition of information increases the salience of the environmental issue to the market, thus legitimating market interest and company investment in green technologies.

Media coverage can affect market attitude and interest through the way in which the information is framed. Specifically, framing events and issues in positive and negative terms provides audiences with visible public expressions of approval or disapproval of industries, firms and their actions (Elsbach, 1994; Lamertz and Baum, 1998). In the case of environmental issues, the framing of media coverage does not seem to have a relevant affect on the takeoff of environmental technologies, in the sense that both positive and negative coverage should generate interest and willingness to buy products having a reduced footprint on the environment. Positive framing raises the visibility of companies implementing environmental sustainable actions, inviting further market attention and scrutiny. On the other side, the threat of negative media publicity can apply coercive pressure to companies to commit to corporate environmentalism by damaging the legitimacy of a firm if the media reveals objectionable actions.

Hypothesis 6: The volume of media-provided information about the environmental subject positively affects the adoption (take-off) of environmental technologies.

However, the relationship between media exposure and salience is not always linear and monotonic, since it has been proved that it exists a threshold level of information exposure above which media exposure is not effective in generating interest anymore and risks to produce a negative reaction (Fiske and Taylor, 1991). Although in the case of environmental technologies the ethical connotation of the issue does not provoke saturation so easily, the linearity of the relationship needs to be verified.

4.4.6 Top management commitment

The development and adoption of innovative environmental technologies is a more comprehensive and socially complex process than simple compliance to regulation.

The tradition of technological evolution literature would use arguments related to firm capabilities in explaining the adoption difficulties. Specifically, given the degree of newness of environmental technologies to the firm, existing technological capabilities, codified in routines, procedures, and information processing capabilities, limit its adaptive intelligence (Nelson and Winter, 1982). In this situation, the role of managerial cognition is essential to break the inertia and trigger the dynamic evolution of technological capabilities (Tripsas and Gavetti, 2000). Additionally, the role of top management is particularly critical due to the fact that the competitive advantage descending from the adoption of environmental technology is long-term. Without a persuasive top management there are limited chances that a company transfers monetary and intangible resources form mainstream technologies to environmental technologies whose return on investment is still much delayed in time.

From a cognitive perspective, top management commitment requires top managers to develop and interiorize a new technological frame according to which the environmental investment (technology) is seen as an appropriate and legitimate opportunity to pursue. Given the dynamics of isomorphism acting within the company and within the industry (competitors and customers), the environment-oriented technological frame can progressively become mainstream. The greater is the degree of institutionalization of the cognitive frame, the greater the uniformity of cultural understanding, the greater the penetration of environmental technologies.

The managerial discretion principle of corporate social responsibility provides further support to the role of top management in the company decision of developing environmental technologies. Accordingly, company's social responsibilities are not met by some abstract organizational actors; they are met by individual human actors (the top management) who constantly make decisions and choices on the strategies at the corporate level (Wood, 1991). In terms of environmental commitment, despite the existence of certain environmental responsibilities prescribed by external subjects (government, competitors, activists,…), managers have choices about how to fulfil many of these responsibilities. This implies that because managers possess discretion, they are personally responsible for deciding whether to adopt a certain environmental technology and to what extent support the environmental commitment of the company.

Obviously the principle of managerial discretion is affirmed within the bounds of economic and organizational constraints. In fact, although top management commitment can be a powerful driver also by itself, in order to be profitable and really contribute to the takeoff of the new environmental technology it has to be coordinated with the availability of complementary resources and capabilities, which the firm should already own (Aragón-Correa, 1998; Aragón-Correa and Sharma, 2003; Christmann, 2000; Hart, 1995).

Hypothesis 7: Top management commitment positively affects the adoption (take-off) of environmental technologies.

4.4.7 Value Net

Among the characteristics of the technological field able to affect the penetration of environmental technologies, the size of the value net is remarkably important. The industry value net consists of suppliers and producers of complementary goods that deliver utility either directly or indirectly to the final consumer (Stabell and Fjledstad, 1998). The technological interdependences within a value net play a major role in the trajectory of technological evolution (Tushman and Rosenkopf,1992; Wade, 1995). The interest of this research is whether and how the size of the value net affects the diffusion of the environmental technologies in a certain industry.

Since the value net typically consists of firms with different, frequently competing objectives, they may initially prefer to support the traditional technology, instead of taking the risk of immediately turning their resources towards environmental technologies characterized by higher levels of performance and market uncertainty. If the takeoff of an environmental technology seems to be inevitable, then the value net will support the leading firms in the development of environmental technologies and contribute to the reduction of the time to the takeoff of an environmental technology. In fact, the more firms adopt an environmental technology, the greater is the incentive for firms in the value net to suspend further investments in product development, and to support the emerging technology. The more firms in the value net support the environmental technologies, the higher is the economic advantage for firms developing the environmental technology, and the higher is the penetration rate of the environmental technology in the industry

Hypothesis 8: The number of firms in the value net of an industry and that support the environmental technology positively affects the adoption (take-off) of environmental technologies.

4.4.8 Market penetration

Many studies showed that market penetration is an important correlate to the takeoff of new technologies (Golder and Tellis, 1997; Golder and Tellis, 2004). Rogers' (1995) research on diffusion of innovations found that markets for new products tend to cross a threshold from innovators to more of a mass market at about 2.5% penetration. Thus, knowing market penetration allows making predictions about the occurrence and the timing of new technology takeoff.

In the case of the environmental technologies, market penetration can be regarded as a factor triggering adoption through imitative behaviours. In the case of environmental technologies, network effects have not been generally detected. However, adoption due to the behaviour of other individuals can occur because of imitative mechanisms. This phenomenon has been referred to as informational cascades, which describe how people converge on adopting a behaviour with increasing momentum and declining individual judgement of the merits of the behaviour, due to their tendency to derive information from the behaviour of prior adopters (Bikhchandani, Hirshleifer, and Welch, 1998). The essence of informational cascades is that even though individuals make decisions on the basis of their own information, they are influenced by the behaviour of other people's decisions.

As people adopt a new technology based on its performance, they provide a signal to non-adopters, who might start adopting the new technology under the influence of the adopters' behaviour. As the number of adopters increases, they provide a progressively stronger signal to the non-adopters, who then adopt in increasing numbers. Consequently, the higher the market penetration of a new technology, the larger the imitation effect, and the quicker the takeoff. This mechanism can be particularly effective in the case of environmental technologies. In fact, since their breakthrough effect is related to an *ethical attribute*, their adoption is much more affected by social mechanisms of imitation and group acceptance, rather than by manifest performance superiority.

The relationship between market penetration and technology adoption could be not linear. Specifically, since after a certain level of market penetration information cascades slow down and the technology reaches the maturity stage of the life cycle, the relationship could be U-shaped.

Hypothesis 8: Market penetration of the environmental technology positively affects its adoption (take-off).

Chapter Five

Methodology and Research Design

5.1 Industry Selection

Two criteria have been used to select the industries for settling the study: the degree of technological innovativeness and the environmental impact. The research focuses on industries with a certain degree of technological innovativeness, intended as the frequency with which new technologies (disruptive and not) are introduced at product and process level.

Additionally, industries with a relevant impact on the natural environment have been considered in order to generate non-zero dependent and independent variables. Prior research indicates that firms in visibly polluting sectors are responsive to environmental issues (Bansal, 2005; Bansal and Roth, 2000).

On the basis of these criteria, the selected industries are: appliances, automotive, and lighting. In the last years, these industries have been characterized by significant changes in variables like amount of pollution, level of public concern, stringency of environmental regulations, and environmental liability risks. As a result, a high amount of innovations tackling the environmental issue has been introduced.

In each industry, the particular environmental technology to regard as disruptive has been chosen on the basis of the knowledge of industry experts, who indicated the relevant technical information and the key milestones in the green evolution of the industries. The industry experts were given a rough idea of the general framework proposed by the present research and asked to identify what could be regarded as the breakthrough green technology in the industry. They were also asked to indicate the approximate date on which the technology was introduced in the market and their opinion on the main factors facilitating the diffusion process.

As a result, the following technologies and time span have been selected for data collection and analysis:

- Automotive industry: the hybrid car from 1999 (year of the introduction of the first hybrid car in the US market) to 2007
- Light bulb industry: fluorescent bulbs and compact fluorescent bulbs (CFL) from 1995 (year of introduction of the T5 standard) to 2007
- Refrigerators (within the appliances industry): from 1993 (year of the federal regulation on energy efficiency) to 2007

For each industry, data have been collected on the main companies developing and commercializing the selected environmental technologies in the US market:

- Hybrid car: Since the automobile industry is very concentrated, data has been collected on all the players launching hybrid models in the US market, namely: Toyota, Honda, Ford, General Motors, Nissan, Chrysler.

- Light bulb industry: The number of CFL manufacturers in the United States has increased a lot since the introduction of the technology. Today there are 93 manufacturers offering 3340 different bulbs (US Department of Energy, 2009). Obviously it was not possible to collect data about each player, given that especially the small companies do not publish a lot of information about their activity and figures. Consequently, only the biggest player have been considered: GE Lighting, Osram Sylvania (Siemens), Philips Lighting.
- Refrigerators (within the appliances industry): Also in this industry there are many players and the chosen option is to consider the main ones: Whirlpool Corp.; General Electric Co. (GE); Maytag Corp (bought by Whirpool in 2006); Sears, Roebuck & Co; and White Consolidated Industries Inc. (the U.S. subsidiary of Electrolux, which owned Frigidaire, Kelvinator, and other familiar brand names). The industry went through a process of progressive concentration, so most of the above-mentioned company owns more than one refrigerator brand. Overall, the analyzed companies had a market share of 69.4% in 2008 (Euromonitor International, 2009)

As to the geographic coverage, the evolution of the environmental technologies has been observed in the United States given the larger availability of data over time, the innovativeness of the country, and the social and institutional sensitivity to the environmental issues.

In the next paragraphs, the environmental technologies are briefly described, together with the key facts in the industries.

5.1.1 Automobile Industry: The Hybrid Car

A hybrid vehicle is a vehicle that uses two or more distinct power sources for moving. While the combination of gasoline and electric engines is quite recent, the origins of hybrid technology actually date to the end of the 19^{th}. However, more than once the technology has been championed as a breakthrough, only to be cast aside when a more convenient alternative emerges.

The world's first hybrid car was Lohner-Porsche petrol-electric "Mixte", built by Ferdinand Porsche in 1902. The first hybrid car used a petrol engine, which rotated at a constant speed to drive a dynamo, which then charged accumulators. The accumulators fed current to electric motors contained within the hubs of the front wheels. Thousands of hybrid cars were produced in the years between 1902 and 1920. However, by 1920 Ford motor company's efficient assembly line manufacturing and the introduction of the self-starting gas engine resulted in a rapid decline for hybrid car production.

After the first successful hybrid cars, it took nearly a hundred years for them to become popular again. The first commercial mass-market hybrid car of the new generation, Toyota Prius, was launched in 1997, in the Japanese market, after many years of technological research and development. Toyota Prius, like most of the other hybrid car introduced afterwards, is a hybrid electric vehicle (HEV), which combines an internal combustion engine and one or more electric motors.

5.1.2 Lighting Industry: Fluorescent Bulbs

Over the last years, the light bulb market has registered some major changes given the increase of environmental pressures. As a result, the older technologies such as incandescent bulbs, have been replaced by more energy savvy technologies like fluorescent (and compact fluorescent bulbs).

A fluorescent bulb is a gas-discharge lamp that uses electricity to excite mercury vapour. The excited mercury atoms produce short-wave ultraviolet light that then causes a phosphor to fluoresce, producing visible light. A fluorescent bulb converts electrical power into useful light more efficiently than an incandescent lamp. Lower energy cost typically offsets the higher initial cost of the lamp. While larger fluorescent lamps have been mostly used in large commercial or institutional buildings, the compact fluorescent lamp is now being used as an energy-saving alternative to incandescent lamps in homes.

Fluorescent bulbs have been introduced into the mass market in the early 1990s. Although they generated diffused interest, the bulbs were too big for many fixtures, expensive (up to $25 each) and they threw a dim, antiseptic light contrasting with to the warmth of traditional incandescent bulbs. Over the years fluorescent bulbs have evolved a lot: new bulbs are smaller, far cheaper (about $5 each) than their predecessors, and more powerful. Top-end 24-watt bulbs promise brightness equivalent to that of a 150-watt incandescent.

5.1.3 Energy efficient and non-CFC refrigerators

The environmental impact of refrigerators depends on both the refrigerant fluorocarbon technology and the amount of energy they use during their lifetime.

Since the beginning of the 90s, manufacturers have attempted to tackle both the problems by replacing the chlorofluorocarbon technology (CFC) with less impacting technologies and by redesigning the refrigeration system in a more efficient way.

As to CFCs, they have been replaced by refrigerant technologies containing less or no chlorine, which is considered the main determinant of toxic emissions and consequent global warming. Newer generations of fluorocarbons, have no or only minimal impact on the ozone layer, while having the same positive characteristics as the CFCs they replace.

However, energy efficiency is a far more significant target for reducing global warming from refrigeration, since it has been calculated that in a typical fluorocarbon refrigeration system, 85% of the global warming impact may come from energy use over its operational life and only 15% from the refrigerant. As a result, in the last twenty years great strides have been made to make refrigerators more energy efficient through deep modifications of their design. In the early 1990s a competition was held among the major manufacturers to encourage energy efficiency. Current models that are Energy Star qualified use 50 percent less energy than models made before 1993

5.2 Data Collection

There is no existing database for studying the take off of environmental technology. Consequently, data have been collected using the historical method, following an emerging trend in marketing. The benefits of using the historical method include lower survival and self-report bias, ability to assess causality through longitudinal analysis, and new insights from a fresh reading of history (Golder, 2000; Tellis and Golder, 1996).

The information required for this study is technical data on the performance of various technologies at different stages of their evolution and data on the behaviour of internal and external variables affecting the evolutionary pattern. The primary sources of data were reports, technical journals, industry publications, white papers published by R&D associations, annual reports, press releases, law databases. Appendix A encloses a list of the main sources used to build the database.

In order to minimize the likelihood of missing important information, the searching process has covered publications that vary in terms of periodicity (i.e., annual, monthly, weekly and daily periodicals), regional coverage (i.e., national and international publications), and perspective (i.e., “insider” annual reports and “outsider” business press articles).

5.3 Measures

Takeoff

The takeoff is the first year in which a product’s growth rate relative to its previous year’s unit sales is higher than a predetermined threshold for takeoff (Golder and Tellis, 2004). Most prior research has identified takeoff using heuristics, such as the rules developed by Golder and Tellis (1997), Stremersh and Tellis (2004), and Tellis, Stremersch and Yin (2003). The spirit of these rules was to call takeoff the first time sales crossed a boundary growth percentage (generally 400%), after the base sales were taken into account. However, since this threshold does not have any theoretical and empirical foundation, this study opts for a measure proposed by Stremersch et al. (2007). Accordingly, takeoff is defined as the year in which the ratio of change on the growth of sales relative to base sales reaches its maximum before the inflation point in sales.

Technological performance (TECH_DISR, TECH_MS)

For each of the three technologies, technological performance has been measured with reference to both the disruptive and mainstream attribute. It has not been difficult to identify these performance dimensions based on the historical description of the technologies. Each performance attribute has fairly clear performance metrics, as indicated in Table 1.

Table 1
Metrics of disruptive and mainstream performance attributes for each technology

	Disruptive attribute	Mainstream attribute
Automotive	•Carbon Footprint (Annual Tons of CO_2) •Fuel efficiency (MPG)	• 0-60 performance (seconds) • Net power (horsepower)
Light Bulbs	• Energy efficiency (Lumens per Watt)	• Light quality (Lumens)
Appliances	• Energy efficiency (Kwh/Year)	• Quality index (Size & functionalities)

For standardization reasons, the value of each attribute has been divided by its initial value. Additionally, the values of carbon footprint and energy efficiency have been reversed in order to test the hypothesis of positive effect of technological performance on technology adoption. Since, in the case of cars it was not possible to identify a prevailing disruptive and mainstream attribute, the performance measures are given by a combination of respectively two disruptive and two mainstream dimensions.

In the case of light bulbs, since CFL bulbs can have several sizes and shapes, the study considers the CFL equivalent of a traditional incandescent bulb of 60 watts. In the case of appliances the study focuses on full size refrigerators.

Price (P)

In order to have a standardized measure of price, the price of each product in each period has been divided by that product's initial price (Golder and Tellis, 1997). Besides allowing for standardization, this choice has also the effect of measuring price relative to the introductory price, which serves as a reference point. There is strong support for incorporating price relative to the introductory prices in econometric models (Kalyanaram and Winter, 1995; Rajendran and Tellis, 1994). All price data are adjusted for inflation.

Regulatory pressure (REG): intensity and type

In order to assess the intensity of regulatory pressure, data from the annual *Enforcement and Compliance Assurance Accomplishment Report* (EPA) have been used (Berrone and Gomez-Mejia, 2009). The procedure consisted in the identification of firms that were defendants in environmental lawsuits and used the number of cases per year as a measure of the strength of regulatory forces faced by the firm in that year. Since institutional forces are not expected to have an immediate effect, regulatory intensity is incorporated with a two years lag. In order to triangulate the EPA report, the number of fines or penalties disclosed in the annual report has been checked Bansal (2005).

In order to observe the effect of different type of regulations (market-based environmental policies versus direct policies; measures oriented towards changes in production processes versus measures oriented towards end-of-pipe abatement), four dummy variables have been used, one for each of the typology tested. The option of using two dummies (one for each duality) has been excluded in order to take into account the possibility that in the same year opposite types of regulations are implemented.

The four dummies correspond to the following typologies:

- Market-based (*REG_MB)*: Pigovian taxes (a tax levied on a market activity to correct the market outcome, if there are negative externalities associated with the market activity), Pigovian subsidies (If there are positive externalities instead of negative externalities, one would want to encourage these behaviours by subsidizing them instead of taxing them), auctioned or grandfathered permits.
- Direct policies (*REG_DP)*: absolute emissions limits, performance standards - such as limits on emissions per unit output or per unit input - or technology standards - such as scrubber requirements (add-on technologies to comply with laws on emissions reduction for example).
- Measures oriented towards changes in production processes (REG_CPP): input-oriented instruments (input bans or input taxes)
- Measures oriented towards end-of-pipe abatement (REG_EPA)

Media pressure (MP)

Media pressure was measured following a procedure already used by Bansal (2005). It incorporates two measures: (1) the total number of articles that include a statement about each of the companies observed, its industry and its environmental issues, which was labelled 'total media'; and (2) the number of articles about the industry with a negative attitude towards their environmental practices, which was labelled 'negative media.' The articles were extracted from the computerized databases of Factiva. The search used keywords that included company names and signals for environmental commitment (environmental, environmental protection, pollution, pollution reduction, pollution prevention, greenhouse gases, emissions, toxic, natural resources, hybrid vehicle, fluorescent bulb, energy savings). All relevant articles were included in total media. Among the relevant articles, those that had a negative orientation were identified and considered for further analysis on the variable.

The choice of a database including specialised press is quite common (Hoffman, 1999). Publications like trade journals offer specialised coverage for specific audiences, providing information through the frames of reference of the focal industry's readership. Trade journals' role in the institutionalisation process is significant in two ways. First, they act as a historical record of key issues and events as perceived from within an industry as well as of the motivating factors behind industry actions. Second, they are themselves organisational players: their output influences issues' interpretation, and they are subject to the political pressures exerted by powerful figures within industries.

Top management commitment (TCM)

To measure top management commitment to the development of environmental technologies, the present study looked at the amount of environmental practices implemented by each company at a corporate level. These practices can be regarded as an outcome of the top management willingness.

For a firm to have a top management commitment score greater than zero, at least one item in a list of environmental practices had to be identified in the company annual report. Practices to be included in the list have been identified by using previous studies (Banerjee et al. 2003; Bansal, 2005; Sharma and Vredenburg, 1998) and are reported in Table 2. The total number of items mentioned in the annual report was summed, and the result was divided by the total number of possible items for environmental commitment.

Table 2 - Practices indicating environmental management commitment

1. Manufactured products that have a less environmental harmful impact than in previous years
2. Manufactured products that have a less environmental harmful impact than its competitors
3. Manufactured products with less environmental damaging inputs than in previous years
4. Manufactured products with less environmental damaging inputs than its competitors
5. Chose inputs from sources that are remediated or replenished
6. Reduced environmental impacts of production processes
7. Eliminated environmentally damaging processes
8. Eliminated operations in environmentally sensitive locations
9. Reduced operations in environmentally sensitive locations
10. Attempted to reduce likelihood of environmental accidents through process improvements
11. Reduced waste by streamlining processes
12. Used waste as inputs for own processes
13. Disposed waste responsibly
14. Handled or stored toxic waste responsibly
15. Voluntary work associated to environmental objectives
16. Allocation of time and financial resources to environmental issues
17. Adoption of more or less preventive technical and organizational measures
18. Existence of an environmental management system
19. Assignment of environmental responsibilities at the firm
20. Preparation of sustainability report

Data were extracted from the annual reports of each company in the sample. All reports were coded by a single rater. To test for reliability, a random selection of 24 annual reports was coded by an independent researcher. Both researchers were familiar with the definition of environmental commitment because it would improve the integrity of the coding process and help to align perceptions. Each factor was coded as ‘0’ or ‘1’, where ‘0’ represents no indication of the item and ‘1’ represents some presence. The codes were compared and inter-rater reliability was satisfactory based on Cohen’s kappa (0.81), so only the codes from the primary coder were used to retain consistency in codes.

The use of annual report data to assess the presence of an issue has been criticized on two grounds: annual reports reflect impression management rather than accurate disclosure, and there may be inconsistencies in the disclosure (McGuire, Sundgren, and Scheneeweis, 1988; Salancik and Meindl, 1984). In spite of these weaknesses, annual reports can be a reliable data source for this study for several reasons. First, assessments of CEM issues from annual reports have been shown to be consistent with the evaluation by third-party agencies (Meek, Roberts, and Gray, 1995). Second, annual reports are unobtrusive, so that firms cannot engage in research specific posturing as they can with interviews or surveys. Finally, annual reports provide an opportunity to collect historical, time-sensitive data that are only otherwise available through employee recall, which is considered unreliable when evaluating the timing of an adoption decision (Van de Ven and Huber, 1990).

Value Net (VN)

The size of the value net has been measured by counting the number of firms connected to the operations of those adopting the environmental technologies. Data has been collected by using the SIC classifications and the SEC´s EDGAR database for firms operating in the US (Srinivasan et al., 2006).

Market penetration (MKTPEN)

For calculating market penetration, the following formula has been used:

$$MKTPEN_t = MKTPEN_{t-1} + \{(sales_t - sales_{t-r})/(households_t)\}$$

where r is the average repurchase time for technologies in a certain category. As average repurchase times during the growth stage, the following approximations have been used: 8 years for automobiles, 10 years for refrigerators, and years for light bulbs. The average repurchase time was estimated by researchers, based on own judgement and consultation with experts, and kept constant over time

5.4 Data analysis: A Model for the Takeoff of Environmental Technologies

In order to test the proposed hypotheses, two different types of analysis are undertaken. First, takeoff analysis techniques (graphical, generalized logistic function, hazard function) are applied in order to make conclusions on the shape of technological evolution and key events like the takeoff and the slowdown in the sales of environmental technologies. Second, a panel data model is conceptualized in order to test the effects of the evolutionary factors on environmental technology adoption over time.

5.4.1 Takeoff Analysis: the Shape of Technological Evolution

Hypothesis 1 predicts that technologies evolve through S-curves. This hypothesis will be tested in two stages. The first one consists in a graphical plot of sales of each environmental technology against time (Sood and Tellis, 2005; Stremersch et al., 2007). The second stage fits the generalized logistic function to the three technologies (Sood and Tellis, 2005):

$$Y_t = d + \frac{a}{1 + e^{-b(t-c)}}$$

where Y_t is the sales if the technology in year t, and a, b, c, and d are the logistic parameters to be estimated: b is the growth rate, c is the time of maximum growth or the inflection point, and a + d is the upper asymptote of the S curve. Nonlinear regression techniques in STATA are used to test the model.

5.4.2 Factors Affecting Technological Evolution: Modelling Takeoff

To examine the temporal pattern of factors affecting technological evolution, the data will be aggregated across industries and companies within the industries, and used for testing the model developed in the following paragraph.

Before introducing the model, some considerations need to be done. First, since the causal effects are analyzed over time and the cause normally needs a certain period of time to generate the effect, all the independent variables in the model will be lagged of one period, with the exception of regulatory pressure (lagged two periods) and price (not lagged).

Secondly, nonlinearities may be expected. Therefore, log-transformation should be used for some variables in order to linearize the model.

Consistently with other studies of technology takeoff (Agarwal and Bayus, 2002; Golder and Tellis, 1997, 2004; Tellis et al., 2003), the time from introduction to slowdown will be modelled as a function of a baseline hazard function and independent variables (the factors included in the framework). The takeoff is a time-dependent binary event. The non-occurrence of the event in the past influences the likelihood of its occurrence in the present. In particular, given favourable conditions, the probability of takeoff increases with the length of time it has not occurred. This phenomenon can be modelled best by the hazard function (Allison 1984; Cox, 1972;

Heckman and Singer, 1984; Helsen and Schnittlein, 1993; Jain and Vilcassim, 1991; Kalbfleisch and Prentice, 1980; Lawless, 1982).

The study will use Cox's (1972) proportional hazard model because it is not constrained by a particular distribution for the baseline hazard function and it allows time-varying independent variables. Accordingly, the time to takeoff for each technology follows its own hazard function, $h_i(t)$, expressed as:

$$h_i(t) = h(t; z_{i,t}) = h_0(t) e^{(z_{it}\beta)}$$

where $h_0(t)$ is an unspecified baseline hazard function, z_{it} is the vector of independent variables for the ith technology, and β is the vector of unknown parameters.

An interpretation of the hazard model is that the baseline hazard function is adjusted by the independent variables of each individual category at each time period. This adjustment occurs by the hazard ratio, which is defined as e^{β}. Positive β coefficients increase the hazard function or probability of takeoff, and negative β coefficients decrease the hazard function. The magnitude of the effect of any independent variable increasing by one unit is $(e^{\beta} - 1) \times 100\%$.

Similar to Helsen and Schmittlein (1993) but unlike Jain and Vilcassim (1991), the present study does not include a term for unobserved heterogeneity. Omitting unobserved heterogeneity does not have serious consequences when only non-repeated events are modelled (Allison, 1984). Since the takeoff can occur only once for each category, the selected approach seems reasonable.

The hazard model will be estimated with a semiparametric partial likelihood method (Helsen and Schmittlein, 1993). The partial likelihood considers the probability that one category experiences the takeoff out of all categories that have not had the takeoff.

Once the general hazard model has been estimated and the key events of takeoff and slowdown have been identified, the influence of the explanatory variables on technological evolution is analyzed in three different periods: introduction, growth, and maturity. In this case, a panel data model is specified, taking the log-transform of specific effects when appropriate (Baltagi, 1995; Greene, 2002; Gujarati, 2004; Wooldridge, 1999). The log-transformation is appropriate given the need to pool data across different technologies that represent different sales in volumes. The dependent variable is the log-transform of unit sales of company *i* in period *t,* denoted as Y_{it}:

$$\log(Y_{i,t}) = \beta_0 + \beta_1(\log TECH\_DISR_{i,t-1}) + \beta_2(\log TECH\_TR_{i,t-1}) + \beta_3(\log P_{i,t}) + \\ + \beta_4(\log REG_{i,t-2}) + \beta_5(\log MP_{i,t-1}) + \beta_6(\log TMC_{i,t-1}) + \beta_7(\log VN_{i,t-1}) + \\ + \beta_8(\log MKT\_PEN_{i,t-1}) + w_{it}$$

where β_0 is a common mean value for the intercept of the individual companies in the panel. The individual differences in the intercept values of each company are reflected in the composite error term w_{it}:

$$w_{i,t} = \varepsilon_i + u_{i,t}$$

where ε_i is the company-specific error component reflecting heterogeneity across the different technologies and controls for time-invariant, unobserved, technology-specific variables.

The model will be estimated following the random effects approach. This choice is based on different reasons. First, both the Breusch and Pagan Lagrange-multiplier test [$\chi^2(8) = .82$, p =.991] and the Hausman test [$\chi^2(1) = 9.26$, p = .00] suggested rejecting a fixed-effects model in favour of a random-effects model. Second, the random effects model is more appropriate in case in which the model includes explanatory variables that change over time, but have the same value for all cross-sectional units. Finally, given the relatively high number of companies and the amount of explanatory variables, the use of a fixed effects model could have generated the degrees of freedom problem.

Table 3 reports the relevant descriptive statistics of the variables included in the panel data model.

Table 3 - The descriptive statistics of the relevant variables

	Correlation								
	1	2	3	4	5	6	7	8	9
1. Sales									
2. Disruptive attribute	-0,40								
3. Mainstream attribute	0,60	0,02							
4. Price	-0,42	-0,16	-0,53						
5. Top management commitment	0,48	-0,19	0,49	-0,49					
6. Regulatory pressure	0,20	-0,22	0,30	-0,25	0,20				
7. Media pressure	0,37	-0,38	0,24	-0,15	0,36	0,32			
8. Value net	0,31	-0,50	0,03	0,13	0,30	0,34	0,61		
9. Market penetration	0,71	0,10	0,53	-0,41	0,38	0,15	0,16	-0,05	
Mean	8,33	0,76	1,29	0,86	0,50	4,15	252,11	139,11	0,28
SD	9,92	0,22	0,38	0,24	0,11	1,70	127,14	82,90	0,81

Chapter Six

Results

6.1 Introduction

The results of the empirical analysis are organized in the following way. First, the findings on the hypothesis regarding the shape and the takeoff of environmental technologies are presented. Afterwards, the hazard function of technological evolution is estimated and the hypotheses of the factors affecting the takeoff are tested. Then, the study compares the impact of the evolutionary forces in different stages of the diffusion process. Finally, the results are discussed with reference to each individual hypothesis.

6.2 The takeoff of environmental technologies: the shape of technological progress

Hypothesis 1 predicts that environmental technologies evolve following an S-curve. The hypothesis has been tested using graphical techniques and statistical fit with the generalized distribution functions.

The graphical analysis consisted in plotting the sales of each technology on the y-axis against time on the x-axis (see Figures 3 to 5).

Figure 3 - Sales evolution for hybrid cars

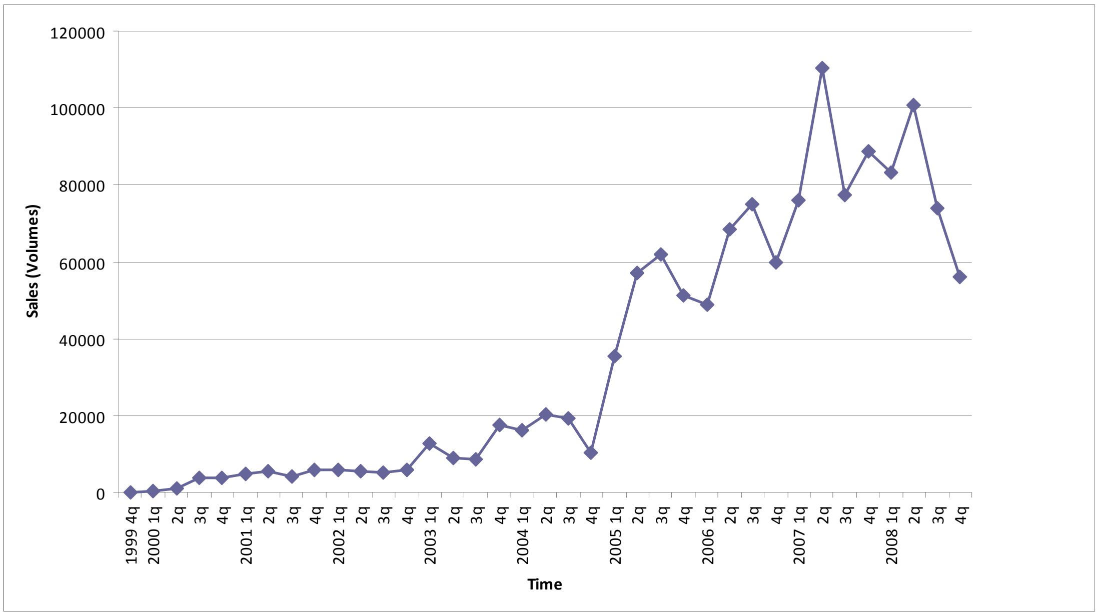


Figure 4 - Sales evolution in energy efficient refrigerators

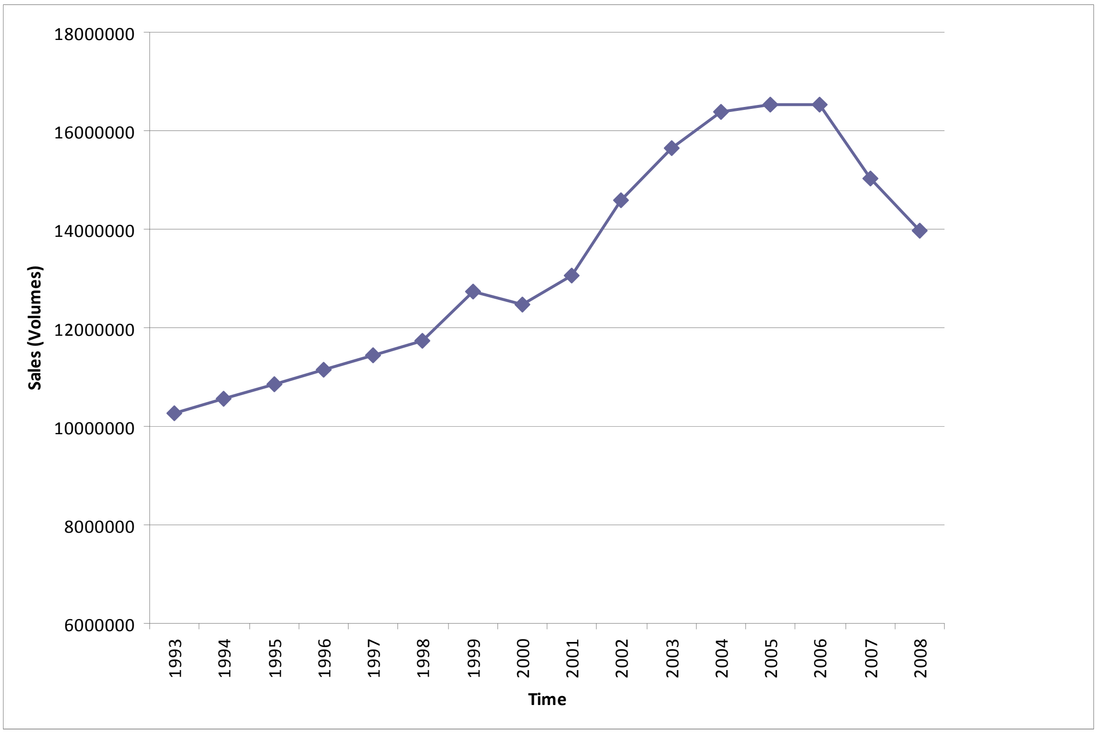
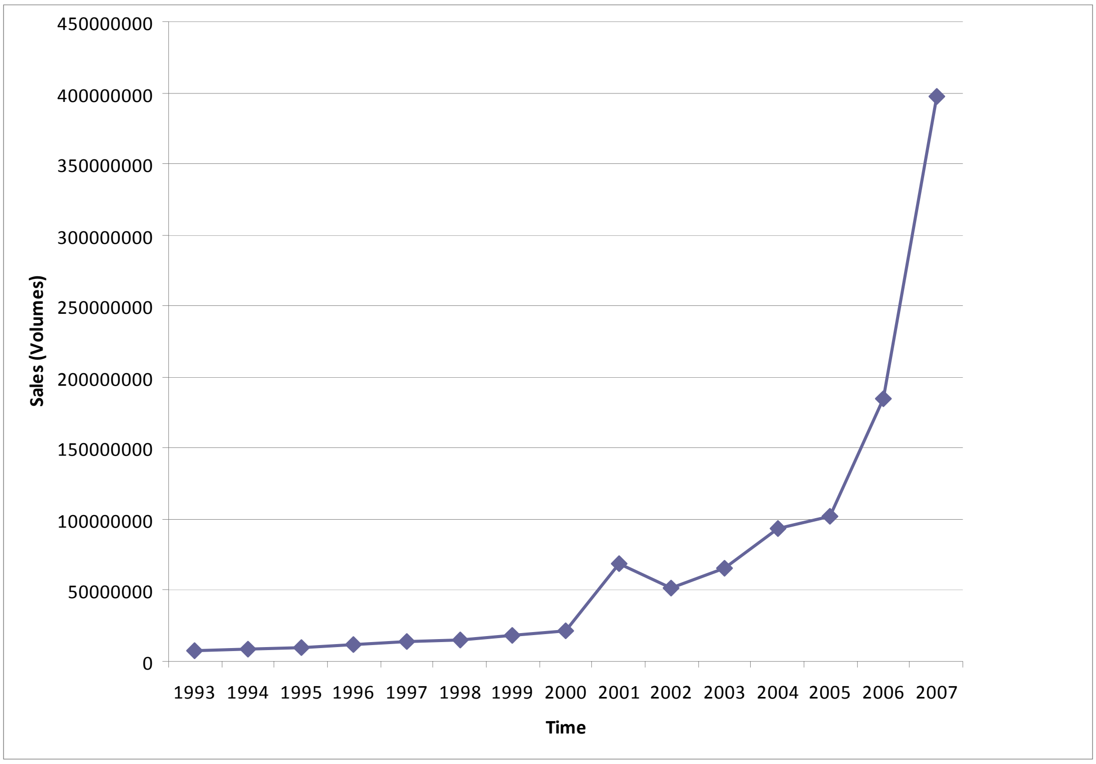


Figure 5 - Sales evolution for CFL bulbs



As hypothesized, these figures show that technologies have a slow start and a sudden growth spur, which represents the takeoff of the new technology. Additionally, in two out of three cases (hybrid cars and refrigerators), the growth stage is followed by a maturity stage characterized by a slowdown in sales. As a result three key moments can be clearly identified in the life cycle of environmental technologies:

- commercialization, which is the first year in which a product incorporating the environmental technology is introduced in the market;
- takeoff, which is the year in which the ratio of change on the growth of sales relative to base sales reaches its maximum before the inflation point;
- and slowdown, which is the first year, of two consecutive years after takeoff, in which sales are lower than the highest previous sales (Golder and Tellis, 2004).

In line with these definitions, Table 6 presents the years of commercialization, takeoff, and slowdown for the three categories.

Table 4 - Key years in technology histories

Product category	Commercialization	Takeoff	Slowdown
Hybrid cars	1999	2005	2007 (3q)
Energy efficient refrigerators	1993	1995	2006
CFL Bulbs	1993	2001	No slowdown in data

These years will be useful for having a deeper understanding of the impact of evolutionary forces in different stages of the diffusion of environmental technologies. However, they do not provide enough information to accept the hypothesis on the shape of the evolutionary pattern. Consequently, the generalized logistic function has been fitted to the three technologies and the results show that it fits the data very well in two cases (refrigerators and CFL) and well in the case of hybrid cars. Table 5 shows the results. Generally, a good fit is given by a high statistical significance of the key parameters of the generalized logistic function (Sood and Tellis, 2005). Consequently Hypothesis 1 is confirmed.

Table 5 - Fit of logistic model to the technologies

	Parameter Estimates	
Product category	Upper Asymptote (t-value)	Growth Rate (t-value)
Hybrid cars	2.57 (2.54)	15.3 (2.01)
Energy efficient refrigerators	1.36 (16.5)	8.67 (12.8)
CFL Bulbs	10.14 (21.12)	.78 (6.3)

6.3 Estimation of the hazard model

Table 6 reports the results of the proportional hazard analyses of sales takeoff. Because of the large number of variables and the potential for multicollinearity, the model is run with each independent variable alone, as well as with all the independent variables together.

The reported coefficients are the hazard ratios, which should be interpreted as the increase in the probability of takeoff occurrence determined by each covariate.

Table 6 - Hazard model results – Hazard ratios

Variables	Individual Models								Full Model
Firm-related factors									
Disruptive attribute	.904*								1.664***
	(.048)								(.31)
Mainstream attribute		1.08**							1.507***
		(.035)							(.231)
Price			.918**						.976
			(.039)						(.307)
Institutional factors									
Regulatory pressure				1.003					.984
				.009					(.01)
Market pressure					1.000				.999*
					(.001)				(.002)
Top management commitment						1.344			2.380***
						(.278)			(.614)
Market related factors									
Value net							1.003		.999
							(.002)		(.000)
Market penetration								1.018*	.815***
								(.011)	(.0342)
Log Likelihood	-369.641	-342.192	-346.908	-371.559	-367.281	-348.9	-368.922	-351.814	-291.869
ρ-square	0,005	0,079	0,067	0,000	0,012	0,061	0,007	0,053	0,215
N=154									

Notes: Significance levels (one-sided): * = $p<0.10$; ** = $p<0.05$; *** = $p<0.01$. Standard errors are in parentheses.

McFadden's (1974) Likelihood Ratio Index (ρ^2) has been used as a measure of model fit ($0 \leq \rho^2 \leq 1$). The Likelihood Ratio Index is calculated as $1\text{-}L(x)/L_0$, where $L(x)$is the log likelihood of the model with the covariates and L_0 is the null model. Following Cohen and Cohen (1983), comparing the ρ^2 of the different models provides an idea of the importance of the factors. In the present case, it seems that the full model is by far the best representation of the takeoff pattern of the environmental technologies.

According to the estimation of the full model, five out of the eight hypothesized effects are significantly different from zero and in the expected direction, namely the performance of the disruptive attribute, the performance of the mainstream attribute, market pressure, top management commitment, and market penetration. The confirmed and not confirmed hypotheses will be discussed in the next paragraph.

To verify the *robustness* of the results, the following checks have been undertaken. First, since the model does not include a term for unobserved heterogeneity, the correctness of this assumption has been verified. Unobserved heterogeneity has been modelled through gamma mixing distribution and it was found very weak. Also, the point estimates and standard errors obtained in the model without heterogeneity were very close to the ones found in a model with gamma mixing. The conclusion is that the model tested in the present study performs satisfactorily as compared to a more complex parametric model with gamma mixing, and thus the initial model specification can be retained.

Additionally, to check for the sensitivity of the results to alternative distributional assumption, the baseline hazard function has been estimated alternatively with a Weibell and logistic specification. The results showed that these alternative distributions do not significantly affect point estimates, nor the standard errors of these estimates.

6.4 Impact of evolutionary factors in different stages of the diffusion pattern

Once the general hazard model has been estimated and the key events of takeoff and slowdown have been identified, the influence of the explanatory variables on technological evolution is analyzed over the entire time span and in three different periods: introduction, growth, and maturity. Estimating the model proposed in the previous chapter with ordinary least squares is not appropriate, because there is evidence of both serial correlation (Wooldridge's [1999] test: F [1,10] = 153.00, p >.00) and heteroskedasticity (modified Wald statistic for groupwise heteroskedasticity: χ^2 [14] = 238.68, p >.00) (Greene, 2003). Therefore, a Prais-Winsten model with panel corrected errors has been used to estimate the equation (Baltagi, 1995), assuming first-order autocorrelation and panel-level heteroskedastic errors. This procedure is also appropriate with unbalanced data sets such as the one created for this study.

The results of the estimation for the entire time period and for the three sub-periods are reported in the following table (Table 7).

Table 7 – Results of the panel data analysis

Variables	Overall	Introduction	Growth	Maturity
Intercept	.669	-1.89*	-20.387	
	(.726)	(1.019)	(19.338)	
Firm related factors				
Log($TECH\_DISR_{1,\,t-1}$)	.809***	1.697***	1.323 ***	.487*
	(.185)	(.559)	(.167)	(.286)
Log($TECH\_MS_{1,\,t-1}$)	.594*	.355**	.074	6.724***
	(343)	(.087)	(.465)	(1.306)
Log($P_{i,\,t}$)	-.128	-.146	-872***	-3.914***
	(.189)	(.640)	(.239)	(1.476)
Institutional factors				
Log($REG_{i,\,t-2}$)	-.009	.067	-.140*	.049
	(.068)	(,179)	(.077)	(.665)
Log($MP_{i,\,t-1}$)	-.281**	.344**	-.011	-.407
	(.124)	(.144)	(.120)	(.649)
Log($TMC_{i,\,t-1}$)	.138	.658*	-.144	2.155**
	(.180)	(.351)	(.201)	(.964)
Market related factors				
Log($VN_{i,\,t-1}$)	.628***	.250	.498***	1.242**
	(.071)	(.175)	(.152)	(.539)
Log($MKT\_PEN_{i,\,t-1}$)	.262***	-.045	.374***	.576**
	(.042)	(.533)	(.067)	(.253)
Adjusted R-square	.85	.71	.69	.88
Number of observations	143	35	87	21

Notes: Significance level (one-sided): * = $p < 0.10$; ** = $p < 0.05$; *** = $p < 0.01$
Standard errors are in parentheses.

For all the models the fit statistics are very satisfactory. The adjusted R-square goes from .69 to .88. The models also seem to properly predict the relationships, since many effects are statistically significant and there are only two effects that are difficult to explain: the negative effect of media pressure in the overall model and the negative effect of regulatory pressure in the growth stage.

The results of the panel data analysis will be deeply discussed in the next paragraph. At this stage, it can be noted that they are consistent with some findings of the hazard model estimation and suggest that some relationships can be more complex than expected. Specifically, similarly to the results of the hazard model estimation, both the disruptive and the mainstream attribute of the environmental technology seem to have a strong effect on the market performance of environmental technology. Additionally, although price is not significant in the overall model, it becomes relevant when looking at the different stages of the diffusion process. An analogous pattern characterizes the effect of top management support on the penetration of environmental technologies.

The estimation of the four models shows stability in parameter estimates. In order to test the robustness of the estimates, alternative estimation methods have been used, namely ordinary least squares, generalized least squares, and generalized method of moments. Additionally, these methods have been tested on different subsamples. All these analysis confirmed the findings of the Prais-Winsten model.

The correlation matrix in Table 3 showed some high correlations among several independent variables. The consequences of these high correlations have been tested in two ways. First, different procedures for assessing multicollinearity have been implemented. All these procedures indicate that the moderate interdependencies among the explanatory variables do not create harmful multicollinearity. The values of the condition indexes are below the suggested threshold of 30, and variance inflation factors (VIF) are below 5. Second, the independent variables that showed a high correlation with another independent variable have been dropped one by one. The resulting parameter estimates are not significantly different from the model that included the dropped variable.

6.5 Discussion of the hypotheses

In the following paragraphs the results of the hazard model estimation will be discussed with reference to each single hypothesis, and integrated with the panel data analysis. It is important to notice how the empirical findings support the role of factors of different nature in the diffusion of environmental technology. Together with the statistics on the goodness of fit, this confirms the appropriateness of a hybrid framework for explaining such a complex phenomenon.

H2a and H2b: Technological performance and product design

The two hypotheses on the role of technological performance on the takeoff of environmental technologies are strongly supported by the estimation of the hazard model. Specifically, the performance of both the environmental attribute and the mainstream attribute positively affect the adoption of environmental technologies in the industry ($hr = 1.664, p < 0.01$ and $hr = 1.507, p < 0.01$). As a result, companies should attempt to combine both the environmental technology and the traditional functionalities in the design of environmental friendly products. Thus, the design challenge for the manufacturers is solving the performance conflicts between environmental attributes and mainstream attributes, since in the case of "ethical" disruptive innovations customers appear to be not ready to renounce to the traditional benefits of certain product categories.

The results of the hazard model are strengthen by the panel data analysis, which provide empirical evidence of the significant role of both disruptive and mainstream attributes in the market adoption of products incorporating environmental technologies. Although the reduced sample size requires caution, the strong beta coefficient of the mainstream attribute in the maturity stage is particularly interesting. In disagreement with the theoretical statements of research on innovation disruptiveness, in the case of environmental technologies the disruptive attribute does not overtake, but rather sums to the traditional one over time.

H3: The role of price

In the overall hazard model, price does not have any effect on the takeoff of environmental technologies, namely its effect on the probability of takeoff is not significant. Thus, H3 is rejected. However, the role of price is statistically significant and with the hypothesized negative sign when tested as a factor affecting the sales of the environmental technologies in the different stages of the diffusion process and with particular strength in the growth and maturity stages.

There are several possible explanations to the behaviour of this variable. The first one refers to the role of price elasticity in the diffusion of new technologies. Marketing literature has given a lot of attention to the role of price elasticity during the product life cycle, and the widespread belief is that price elasticity to the adoption of a new product begins low and then increases as the life cycle reaches maturity (Parker and Neelamegham, 1997). This is due to the fact that early adopters are driven by their enthusiasm for the innovation and do not normally care about price. Once the innovation reaches the mass of non-innovator, price becomes important: late adopters are price-sensitive and they expect the increased competition in the new market to generate price advantages to them. A similar behaviour can characterize the diffusion of environmental technologies: the early adopters are the environmental conscious customers who privilege the ecological benefit of the new technology over its price. Once the environmental technology takes off, it reaches the late adopters whose price sensitivity is higher than their environment sensitivity.

However, in the case of environmental technologies, price sensitivity might not be the only determinant of the adoption decision. Regulations or public opinion could be relevant as well, in the sense that with different incentives they foster the environmental consciousness of the customer to a point that it overtakes his/her price sensitivity. Additionally, consumers could start developing a long-term perspective (as it happened in the case of light bulbs) and base their purchase decision on the lifetime cost of the environmental technology rather than on its price. This behaviour is consistent with the general result of no significant effect of price on the probability of takeoff of environmental technologies.

Nevertheless, this discussion suggests that the relationship between price and the takeoff of environmental technologies is much more complicate than the modelling proposed in this research and should be analyzed in further detail.

H4 and H5: Intensity and type of regulatory pressure

The hypothesis on the impact of environmental regulations has interesting implications and needs further exploration. The estimation of the general hazard model does not provide support to the role of regulatory intensity on the probability of technological takeoff, thus leading to the rejection of H4. Additionally, also when testing the effect of regulatory intensity on sales in different stages of the diffusion process, the results are not satisfactory (regulatory intensity is significant only in the growth stage, but with a negative sign). This is surprising, since previous literature on environmental commitment generated evidence on the fact that stringency of public policy regime is generally the most significant influencer on environmental performance, together with technological innovation.

Some explanations can be proposed. First, contrarily to this research, previous studies generally used self-reported data describing a "perceived" stringency of regulatory pressure. The ambiguity and bias of perception-based measurement could have affected the results of previous studies.

Secondly, the present research tested the direct relationship between environmental regulations and the diffusion of environmental technologies. However, the complexity of the issue suggests the existence of indirect relationships between the two variables, for example related to the different environmental management, marketing strategy, and product policy adopted by companies subjected to a certain policy, or to the different market characteristics of the industry in which the measures are introduced. This is consistent with the theoretical perspective of Suarez (2004), according to which certain external factors moderate the effect of firm factors on the emerging of a dominant design.

Finally, the general results may suggest that instrument choice might be more significant than the overall pressure in determining the adoption of environmental technologies. The test of hypotheses H5a and H5b on the type of regulatory pressure can provide useful information.

The four dummy variables for the different types of environmental policies have not been included in the estimation of the general hazard model for parsimony reasons. Consequently, another hazard model has been estimated including only the four dummies and the variable measuring the intensity of regulatory pressure (REG). Additionally, the moderating effect of regulation intensity on the regulation type has been tested, in order to shed light on the previous results on the role of regulatory intensity on the takeoff of environmental technologies. The results are reported in the following table (Table 8).

Table 8 - Hazard model results for regulatory intensity and type- Hazard ratios

Variables	Model 1	Model 2
Firm related factors		
Regulatory pressure (REG)	.991	.888
	(.016)	(.075)
Marked-based policies (REG_MB)	1.188***	.654
	(.072)	(.172)
Direct policies (REG_DP)	1.146**	1.041
	(.076)	(.189)
Changes in production process (REG_CPP)	1.025	.578*
	(.051)	(.164)
End-of-pipe abatement policies (REG_EPA)	.904*	1.998**
	(.053)	(.559)
Interaction effects		
REG x REG_MB		1.418**
		(.075)
REG x REG_DP		.973
		(.037)
REG x REG_CPP		1.101*
		(.062)
REG x REG_EPA		.874**
		(.047)
Log Likelihood	-358.519	-334.313
ρ-square	0.04	0.10
N=154		

Notes: Significance level (one-sided): * = $p < 0.10$; ** = $p < 0.05$; *** = $p < 0.0$
Standard errors are in parentheses.

With reference to H5a (market-based incentives have a stronger impact on the adoption of environmental technologies than direct policies), the findings show that both the policies have a positive effect on the takeoff of environmental technologies, but market-based incentives are better effective when regulatory pressure is more intense. In other words, when the government wants to increase its regulatory pressure in order to foster the acceptance of environmental technologies, it should better opt for market-based policies. Thus, H5a receives partial support from the data.

As to H5b (Measures oriented towards changes in production processes have a stronger impact on the adoption of environmental technologies than measures oriented towards end-of-pipe abatement), it is not confirmed by the data, since end-of-pipe abatement policies seem to be more effective, and under higher regulatory intensity both the policy types are effective.

To sum up, different types of regulatory policies are able to affect the probability of environmental technology takeoff, and their effect interacts with the intensity of the regulatory pressure. Additionally, more flexible instruments appear to play a role in encouraging environmental technology adoption, but their effectiveness is conditional to regulatory stringency. In different words, the government should attempt to create a regulatory environment that is on the one hand supportive to environmental innovation, and on the other hand strict enough to ensure the commitment and the overall environmental quality.

H6: Media pressure

Hypothesis 6 postulating a positive impact of media pressure on the takeoff of environmental technologies is supported by the hazard model (*hr=0.999, $p < 0.1$*). This is consistent with previous empirical studies (Bansal, 2005; Bansal and Roth, 2000; Henriques and Sadorsky, 1996), whose results confirmed that the media has been particularly influential on corporate environmental performance. However, no conclusion can be made on the time-related effects, since media intensity is almost never significant and has an unexpected negative sign.

Considering the findings of the previous hypothesis, it can be concluded that institutional variables generally play a significant role in the takeoff and diffusion of environmental technologies. However, their effect is more complex than what has been shown by previous studies, and requires further exploration.

H7: Top management commitment

Hypothesis 7 is strongly supported by the results of the hazard model estimation (*hr = 2.38, p<0.01*). This finding provides an interesting contribution to both the research on environmental management and technology management, which rarely included this variable in their empirical frameworks. As to the research on environmental management, the results imply that management willingness should be added to internal and institutional factors as a main determinant of environmental commitment, similarly to what is already taken for granted in the corporate social responsibility field (Wood, 1991). As to the research on technological evolution from a management perspective, the present results support the integration of cognitive factors in theoretical modelling of technological evolution.

H8: The role of the value net

Hypothesis 8 is not supported by the data, implying that a growing value net does not increase the probability of environmental technology takeoff. A possible explanation is in the fact that some members of the value net (suppliers) might have difficulties in adopting the new technology, given their skills and complementary assets.

However, the time series results suggest that the value net size can play a significant role in speeding the diffusion of environmental technologies in the growth and maturity stage. This outcome is possibly connected with the strong role played by price in the same stages of the diffusion process. In fact, the broader the value net, the higher the opportunities of cost economies for technology manufacturers and the higher the chances for price decline of products incorporating environmental technologies.

H9: Market penetration

The estimation of the hazard function provides support for the role of market penetration in increasing the chances of environmental technology takeoff ($hr = .815$, $p < .01$). Theoretically, the most notable result is that there is evidence of imitative effects in industries in which environmental technologies are introduced. Consequently, environmental technologies will diffuse in the market not only because of their technological performance, but also due to information cascades among different segments in the market. The analysis of the panel data results does not provide any useful information on the impact of this variable over time.

Chapter Seven

Conclusions

7.1 Introduction

The objectives of this dissertation are to shed light on the difficult takeoff of environmental technologies and, at the same time, to contribute to the general understanding of new technology adoption. For accomplish this purpose, data have been collected on three environmental technologies (hybrid car, CFL light bulbs, and energy efficient refrigerators) in order to observe the takeoff phenomenon and the factors affecting different stages of the diffusion process.

In the following paragraphs the most relevant findings are discussed by relating them to the research questions and to the research gaps that have been detected in the existing literature on both technological evolution and environmental management.

7.2 The time and the shape of environmental technology takeoff

The results of the present study confirm the fact that environmental technologies have a pattern of initial diffusion characterised by a point of rapid sales increase, which represents the takeoff. The takeoff is not instantaneous and requires patience and careful planning on the part of managers. Two out of three industries show a longer takeoff time compared with the results of similar studies in different technological context. Golder and Tellis (1997) found that the average time to takeoff is six years for post-World War II categories. This dissertation found that hybrid cars needed six years to take off, while CFL light bulbs needed. Considering that the pace of technological change in the time frame analyzed in this study is faster than in the period considered by Goder and Tellis (1997), the takeoff of environmental technologies can be regarded as slower than the one of technologies not incorporating an ethical attribute. The case of the refrigerator shows a relatively faster time to takeoff, but the result could be due to the fact that the technological innovation has been introduced some years before 1993 and it was not possible to collect reliable data for the years before 1993. Obviously the reduced number of industries included in this study does not allow to generalize these findings, but they suggest a trend that should be analyzed deeper with further research.

7.3 The evolutionary factors accelerating the takeoff

In the area of technology management many studies have tried to capture the relevant factors that drive new technology takeoff (Suarez, 2004). As discussed in Chapter Two, the issue has been addressed by different theoretical perspectives, thus producing a wide range of frameworks explaining the phenomenon. However, most studies focused on limited sets of factors affecting technological adoption (firm-related, institutional, cognitive), while the complexity of the phenomenon requires a more holistic approach. A similar pattern has been followed by the literature on environmental management, which used to address the issue of environmental commitment alternatively from a resource-based-view (Hart, 1995; Klassen and Whybark, 1999; Russo and Fouts, 1997) and an institutional perspective (Hoffman, 1999; Jennings and Zandbergen, 1995; Prakash, 1999). Recently, researchers in this area recognized the need for a more integrative perspective on firm commitment to environmental technologies (Oliver, 1997). This dissertation proposes and tests a holistic model for the takeoff of environmental technologies that explicitly captures the effects of factors of different nature. Additionally, the substantive domain – environmental technologies – is a new type of disruptive technology, which is going to substantially influence and, in some industries, even change strategic and marketing practices. Therefore, environmental technologies deserve investigation in their own right. Despite the relevant and wide-reaching effects of environmental issues on business practices, there is limited academic research in innovation in the environmental area. By using environmental technologies as a context for testing the proposed framework, this article also contributes to the still limited academic literature on the diffusion of environmental technologies.

As the results show, the performance of both the environmental attribute and the traditional attribute of the new technology is positively associated with the probability of technology takeoff. Therefore, investment in designing a product that is competitive in both the dimensions of technological performance is helpful to the development of the entire industry. An explanation for this could be found in the nature of consumers opting for environmental technologies. Although the customer is generally seen to be a key actor, in many cases consumers actually have very little knowledge about environmental issues, as well as low awareness or low level of prioritization (Fineman and Clarke, 1996; Foster and Green, 2000), so that focusing exclusively on the environmental dimension of new products incorporating environmental technologies might not be an effective marketing strategy. A recent study by Irwin and Naylor (2009) has shown that consumers express their ethical values more in exclusion that in inclusion modes of consideration set formation when buying a product. In other words, the superiority in an ethical attribute is used to exclude alternatives from the choice set, rather than for including alternatives in the choice set. Applying these findings to the particular context of environmental technologies, consumers tend to exclude from their choice set those technologies underperforming in the environmental attribute, but their final purchase decision might still be driven by technological superiority in the mainstream performance attribute. Unfortunately for industries hoping to encourage increased consideration of ethical products, marketplace (e.g., retail) consideration set formation is probably often accomplished by inclusion. Although exclusion may be a natural mode of consideration set formation for product categories with smaller numbers of items, inclusion appears to be the default for larger assortments (Heller, Levin, and Goransson 2002; Levin et al. 2001). In the crowded marketplace of the industries included in this study, it is likely that many consumers are naturally including items when forming consideration sets and thus are not expressing their ethical values as much. As a result, manufacturers of environmental technologies need to launch products that are satisfactory in both environmental performance and performance in the traditional attributes. This conclusion highlights how the issue of compatibility of environmental technologies with non-environmental attributes is central to the development of the considered industries and to the diffusion of environmental technologies in general.

The significance of top management commitment suggests that the role and the values of the board could represent an important source of difference between environmental leading companies and ordinary companies. In order to achieve the acknowledgement of corporate values inherent in environmental commitment, activities like the formal declaration of values and principles in the form of a code of conduct are common. Through these tools, top management can foster both internal commitment and external acceptance of environmental technologies.

The effects of environmental policy stringency, enforcement mechanisms and instrument choice on environmental performance remain imperfectly understood. Contrarily to the results of previous research, the type of regulatory tool seems to be more important than the stringency of regulatory pressure in increasing the probability of environmental technologies takeoff. This finding is consistent with some recent research in the area (DeCanio 1998; Gabel and Sinclair-Desgagné 2001), which has highlighted the importance of designing and implementing public environmental policies in a way that fits the firm's commercial motivations, decision-making procedures and organizational structure when. This is significant since environmental management has become the target of important government policy initiatives, with public authorities assuming that more comprehensive environmental management encourages improved environmental performance. However, it is not clear what policy incentives are effective in encouraging the introduction of environmental management practices, which have a distinct and causal role in bringing about, improved environmental performance. This is an area in which there is much policy experimentation, and empirical evidence is much needed. One of the key determinants of improved environmental performance in the long run is clearly technological innovation. Through investments in environmental research and development firms can identify innovative means of addressing pressing environmental problems. However, the costs incurred can be considerable. Clearly, policy stringency – by changing relative prices or introducing production constraints – will induce innovation of some kind. However, instrument choice may also play a role. If firms are to search for innovative solutions through investment in R&D their returns are likely to be greater if more flexible policy instruments are implemented rather than prescriptive measures, allowing for broader potential application of any innovations discovered. In addition, the implementation of advanced environmental management practices may both lower the potential costs of R&D and increase its benefits.

7.4 The impact of evolutionary factors over time

As shown by the results and the discussion in the previous chapters, the takeoff of environmental technologies follows a defined pattern in which different evolutionary forces interact over time. Table X summarizes the main findings, by indicating the factors that tend to have the strongest effect in each phase.

Table 9 - Key factors of success at each stage of the diffusion

	Introduction	Growth	Maturity
Firm related factors			
Disruptive attribute	***	***	*
Mainstream attribute	**		***
Price		***	***
Institutional factors			
Regulatory pressure		*	
Media pressure	**		
Top management commtiment	*		***
Market related factors			
Value net		***	**
Market penetration		***	**

As the discussion in the previous chapter has shown, the three milestones in the diffusion process (commercialization, takeoff, and slowdown) define the phases that have different characteristics. In particular, success in each phase seems to respond to a different mix of factors of different nature.

Obviously, it is not possible to claim that the diffusion pattern of every environmental technology will conform to these findings. However, the proposed model captures the main forces behind the difficult takeoff of many environmental technologies, and, thus, can provide clarity around this complex issue.

At a more general level, an in depth look at the takeoff process suggests that the adoption of new technologies is the result of thought actions on specific factors that have a particular importance in a certain phase of the process. Prior research has given limited attention to the different stages of the technology diffusion process, especially from an empirical perspective. The present study addresses this gap, by showing that different factors are significant in different stages of the diffusion process of new technologies. In this way it provides an empirical answer to the proposition that the resulting equilibrium in a technological battle is especially sensitive to chance events early in the life cycle (Arthur, 1989; Schilling, 1998). For example, in the introduction stages factors under the control of the company have the highest impact on the market performance of the environmental technologies. As pointed out in the previous chapters, the capability of balancing the performance of the environmental technology on both the disruptive and the mainstream attribute seems to be the key for market success in all the stages of the diffusion process.

Additionally, the findings suggest that institutional pressures can exist in early years and that their role in the organizational and industry change process, as in the case of the media, can be of declining importance. Institutional pressures may have been important in early years because of the ambiguity associated with the meaning, measurement, and impact of environmental technologies.

As environmental technologies become increasingly institutionalized, the resource-based opportunities become more transparent. Consequently, firm related factors increase their relevance. For example, pricing decisions assume a critical role in the diffusion of environmental technologies. While in the introduction stage early adopters were driven by the superior environmental performance of the new technology, in the growth and maturity stage, pricing has the strongest effect. This is due to the fact that when no firm has yet achieved the advantage of a large installed based or a clear technological superiority, market's decisions are likely to be strongly influenced by price.

In the growth and maturity stage, market factors like the size of the value net gain importance. It is at this stage that competing actors need to secure further support for their specific trajectories in the form of complementary goods or services. Even though firms start looking for support to their new technologies even before their commercialization, producers of complementary goods often wait for the technology to take off before giving their full commitment and support.

7.5 Managerial Implications

The findings of this study have also clear implications for managers, particularly in firms developing and commercializing environmental technologies.

On the one hand, the framework tested in this study indicates the different factors that affect technology performance, separating those that firms can directly control from the external factors that are mostly beyond firm's influence. A comprehensive spelling out of the different factors at play in the diffusion process of environmental technologies (and new technologies in general) is by itself particularly valuable, as different streams of literature have tended to place the emphasis on various sub-sets.

On the other hand, the present study enables managers to watch for three key milestones and three key stages in the process, each with its own dynamics and sets of factors that are more likely to prevail. For example, since the balance between the performance in the mainstream and disruptive attribute is key in the introduction stage, managers may want to follow their firms' R&D and product design more closely in order to ensure the achievement of this balance. Moreover, a correct understanding of the ways in which environmental factors constrains managerial action – for example through different types of regulation or through informational cascading effects – can help managers to time their strategic efforts better. A proper understanding of the "window of opportunity" for environmental technologies in the market is essential to the effectiveness of firm-level actions and to the final takeoff of environmental products. As in the case of other technologies, the takeoff of environmental technology is the result of a complex and peculiar interrelation between managerial decisions and environmental factors that together influence the market. A better understanding of which levers to pull and which factors to act upon at each stage of the process is a key capability that firms have to develop when dealing with new technologies.

7.6 Limitations and future research

This study has some obvious limitations, some of which need to be mentioned.
First, the analysis has been limited to only three categories because of the time-consuming nature and difficulty of data collection. Further research should use the general framework presented here to analyze several different product categories, in the particular context of environmental technologies as well as in a more general context.
Second, it was not possible to collect data before 1993 for appliances and lighting. Although the environmental technologies begun to appear some years before, it was difficult to find data for many of the variables included in the model. Thus, some of the time observations were dropped from the panel. This problem especially affected refrigerators, since the time-to-takeoff may have been longer if data from previous years were included.
Third, it was not possible to find consistent measures of certain variables that could have been usefully added to the framework. Consequently, the study was unable to assess the role of important variables that managers can control to trigger take off. An

example of that is the communication policy of companies included in the panel, which has been often regarded as a key factor in new technology takeoff. Considering the data sources available, there was no reliable and valid way to measure this variable.

Despite these limitations, the empirical findings appear to be both intuitive and robust. Furthermore, the general framework developed is flexible enough to incorporate a variety of alternative covariates in different and broader settings. Accordingly, further research is strongly encouraged. In fact, important resource-based and institutional variables that explain environmental technology adoption have been omitted. In addition, there is likely a complex interactive relationship between the different types of explanatory variables, especially when the technology being explored is disruptive in nature, it is defined ambiguously, and its adoption is uncertain. This research highlights the opportunity to investigate not only the relative importance of the internal and external factors over time, but also how the forces reinforce each other, and how this interaction affects change.

Appendix A

Selected sources for data collection

Hybrid cars

American clean car

Automotive design and production

Automotive engineer

Automotive industries

Automotive industry litigation reporter

Automotive news

Motor age

Motor trend

www.hybridcars.com

www.fueleconomy.gov

www.afdc.energy.gov

www.nada.org

Refrigerators

Appliance design

Appliance manufacturer

Home appliance yearbook

Appliancemagazine.com

www.waptac.org

Kitchen & Bath Business

appliancejournal.com

www.homeenergy.org

CFL Light Bulbs

Electrical contractor

Electrical wholesaling

www.homeenergy.org

Electric light and power

Electric perspectives

The electricity journal

Lighting dimensions

Lighting Research & Technology

Architectural lighting

References

Abernathy W.J., Clark K.B. 1985. Mapping the winds of creative destruction, *Research Policy*, 14(1): 3-22.

Abernathy W.J., Utterback J.M. 1978. Patterns of industrial innovation, *Technology Review,* 80(7): 40-47.

Acha V., 2004. Technology Frames: The Art of Perspective and Interpretation in Strategy, *SPRU Working paper series*, #109.

Adner R. 2002. When are technologies disruptive? A demand-based view of the emergence of competition, *Strategic Management Journal*, 23: 667-688.

Agarwal R. 1998. Evolutionary trends of industry variables, *International Journal of Industrial Organization*, 16 (July): 511-525.

Agle B.R., Mitchell R.K., Sonnenfeld J.A. 1999. Who matters to CEOs? An investigation of stakeholder attributes and salience, corporate performance, and CEO values, *Academy of Management Journal*, 42 (Oct), 507-529.

Aldrich H.E., Fiol C.M. 1994. Fools rush in? The institutional context of industry creation, *Academy of Management Review*, 19:645-670.

Allison P.D. 1984. *Event History Analysis*, Sage University Papers, Newbury Park, CA: Sage Publications.

Amit R., Zott C. 2001. Value creation in e-business, *Strategic Management Journal*, 22(6-7), 493-520.

Anderson P., Tushman M.L. 1990. Technological discontinuities and dominant designs: a cyclical model of technological change, *Administrative Science Quarterly*, 35 (4): 604-633.

Aragón-Correa J.A. 1998. Strategic proactivity and firm approach to the natural environment, *Academy of Management Journal*, 40(2): 556-567.

Aragón-Correa J.A., Sharma S. 2003. A contingent resource-based view of proactive corporate environmental strategy, *Academy of Management Review,* 28(1): 71-88.

Aragón-Correa J.A., Matías-Reche F., Senise-Barrio M.E. 2004. Managerial discretion and corporate commitment to the natural environment, *Journal of Business Research*, 57: 964-975.

Arthur B. 1989. Competing technologies, increasing returns, and lock-in by historical events, *Economic Journal*, 99: 116-131.

Baltagi B.H. 1995. *Econometric Analysis of Panel Data*, New York: John Wiley and Sons.

Banerjee S.B., Iyer E.S., and Kashyap R.K. 2003. Corporate environmentalism: antecedents and influence of industry type, *Journal of Marketing*, 67 (April): 106-122.

Bansal P. 2003. From issues to actions: The importance of individual concerns and organizational values in responding to natural environmental issues. *Organization Science*, 14 (5): 510-527.

Bansal P. 2005. Evolving sustainably: a longitudinal study of corporate social development, *Strategic Management Journal*, 26: 197-218.

Bansal P, Clelland I. 2004. Talking trash: legitimacy, impression management and unsystematic risk in the context of the natural environment, *Academy of Management Journal,* 47(1): 93–103.

Bansal P, Roth K. 2000. Why companies go green: A model of ecological responsiveness, *Academy of Management Journal* 43(4): 717–736.

Barney J.B. 1986. Strategic factor markets: expectations, luck and business strategy. *Management Science,* 32 (10): 1231–1241.

Barney J.B. 1991. Firm resources and sustained competitive advantage. *Journal of Management,* 17: 99–120.

Barney J.B. 1995. Looking inside for competitive advantage. *Academy of Management Executive,* 9(4): 49–61.

Bass F. 1980. The relationship between diffusion rates, experience curves, and demand elasticities for consumer durable technological innovations, *Journal of Business*, 53 (2): S51-S67.

Baum J.A.C., Powell W.W. 1995. Cultivating an institutional ecology of organizations: Comment on Hannan, Carroll, Dundon and Torres, *American Sociological Review,* 60: 529-538.

Berger IE., Cunningam PH., and Drumwright ME. 2007. Mainstreaming Corporate Social Responsibility: developing markets for virtue, *California Management Review*, 49 (4): 132-157.

Brunnermeier S.B., Cohen M.A. 2003. Determinants of environmental innovation in US manufacturing industries, *Journal of Environmental Economics and Management*, 45: 278-293.

Bowen F. 2000. Environmental visibility: A trigger of green organizational response?, *Business Strategy and the Environment* 9(2): 92–107.

Buysee K., Verbeke A. 2003. Proactive environmental strategies: A stakeholder management perspective, *Strategic Management Journal*, 24: 453-470.

Charitou C.D., Markide C.C. 2003 Responses to disruptive strategic innovation, *Sloan Management Review*, 44(2): 55-63.

Chen C. 2001. Design for the environment: a quality-based model for green product development, *Management Science*, 47(2): 250-263.

Christensen C.M. 1997. *The Innovator's Dilemma*, Boston: Harvard Business School Press.

Christensen C.M., Bower J.L. 1996. Customer power, strategic investment, and the failure of leading firms, *Strategic Management Journal*, 17(3): 197-218.

Christensen C.M., Rosenbloom R.S. 1995. Explaining the attacker's advantage: technological paradigms, organizational dynamics, and the value network, *Research Policy*, 24: 233-257.

Christensen C.M., Raynor M.E. 2003. *Innovator's Solution*, Boston: Harvard Business School Press.

Christmann P. 2000. Effects of the 'Best Practices' of environmental management on cost advantage: The role of complementary assets, *Academy of Management Journal*, 43(4): 663-680.

Christmann P. 2004. Multinational companies and the natural environment: determinants of global environmental policy standardization, *Academy of Management Journal*, 47(5): 747-760.

Christmann P., Taylor G. 2001. Globalization and the environment: determinants of firm self-regulation in China, *Journal of International Business Studies*, 32: 438-458.

Christmann P., Taylor G. 2002. Strategies for international voluntary environmental initiatives, *Academy of Management Executive*,16 (3): 121-135.

Churchman C.W. 1963. *The System Approach and Its Enemies*, Basic Books: New York.

Clark K.B. 1985. The interaction of design hierarchies ad market concepts in technological evolution, *Research Policy*, 14: 235-251.

Cordano M., Frieze I.H. 2000. Pollution reduction preferences of US environmental managers: Applying Ajzen's theory of planned behavior, *Academy of Management Journal*, 43: 627-641.

Cox D.R. 1972. Regression models and life-tables*, Journal of the Royal Statistical Society* B, 34, 187-200.

Danneels E. 2004. Disruptive technology reconsidered: a critique and research agenda, *Journal of Product Innovation Management*, 21: 246-258.

Dasgupta S., Hettige H., Wheeler D. 2000. What improves environmental compliance? Evidence from Mexican industry, *Journal of ENvironmental Economics and Management*, 39: 39-66.

De Cicco J., Thomas M. 1999. A method for green rating of automobiles, *Journal of Industrial Ecology*, 3 (1): 55-76.

Deephouse D.L. 1999. To be different, or to be the same? It's a question (and theory) of strategic balance, *Strategic management Journal*, 20: 147-166.

Dierickx I., and Cool K. 1989. Asset stock accumulation and sustainability of competitive advantage. *Management Science,* 35 (12): 1504–1514.

DiMaggio P.J., Powell W.W. 1983. The iron cage revisited: Institutional isomorphism and collective rationality in organizational fields, *American Sociological Review*, 48: 147-160.

Dooley R. S., Fryxell G. E. 1999. Are conglomerates less environmentally responsible? An empirical examination of diversification strategy and subsidiary pollution in the U.S. chemical industry, *Journal of Business Ethics*, 21: 1-14.

Dosi G. 1982. Technological paradigms and technological trajectories. A suggested integration of the determinants and directions of technical change. *Research Policy* 11: 147-162.

Drumwright M.E. 1994. Socially responsible organizational buying: Environmental concern as a noneconomic buying criterion, *Journal of Marketing*, 58 (July): 1-19.

Elsbach K.D. 1994. Managing organizational legitimacy in the California cattle industry: The construction and effectiveness of global accounts, *Administrative Science Quarterly*, 39: 57-88.

Euromonitor International, 2009. *Refrigeration Appliances – USA.*

Farrell J., Saloner G. 1986. Installed base and compatibility: innovation, product preannouncements, and predation, *The American Economic Review*, 76: 940-954.

Fineman S., Clarke K. 1996. Green stakeholders: Industry interpretations and response, *Journal of Management Studies*, 33 (6): 715-730.

Fiske S.T., Taylor S.E. 1991. *Social Cognition* (2nd edition), New York: McGraw-Hill.

Flannery B.L., May D.R. 2000. Environmental ethical decision making in the US metal-fishing industry, *Academy of Management Journal*, 43: 642-662.

Foster R. 1986. *Innovation: The Attacker's Advantage.* New York: Summit Books.

Foster C., Green K. 2000. Greening the innovation process, *Business Strategy and the Environment*, 9: 287-303.

Frooman J. 1999. Stakeholder influence strategies, *Academy of Management Review*, 24 (2):191-205.

Garud R., Rappa M.A., 1994. A socio-cognitive model of technology evolution:

The case of cochlear implants. *Organization Science*, 5(3): 344–362.

Garud R., Jain S., Kamaraswamy A. 2002. Institutional entrepreneurship in the sponsorship of common technological standards: the case of Sun Microsystems and Java, *Academy of Management Journal*, 45: 196-214.

Gawer A., Cusumano M. 2002. *Platform Leadership: How Intel, Microsoft, and Cisco Drive Industry Innovation*, Harvard Business School Press: Harvard.

Gilbert C. 2003. The disruption opportunity, *Sloan Management Review*, 44(4): 27-32.

Godfrey P.C. 2005. The relationship between corporate philanthropy and shareholder wealth: A risk management perspective, *Academy of Management Review*, 30: 777-798.

Golder P.N. 2000. Historical method in marketing research with new evidence on long-term market share stability, *Journal of Marketing Research*, 37 (May): 156-172.

Golder P.N., Tellis G.J. 1997. Will it ever fly? Modelling the takeoff of really new consumer durables, *Marketing Science*, 16(3): 256-270.

Golder P.N., Tellis G.J. 2004. Growing, growing, gone: cascades, diffusion, and turning points in the product life cycle, *Marketing Science,* 23(2): 207-218.

Govindarajan V. and Kopalle P.K. 2006. The usefulness of measuring disruptiveness of innovations ex post in making ex ante predictions, *Journal of Product Innovation Management*, 23:12-18.

Grant R.M. 1991. The resource-based theory of competitive advantage. *California Management Review,* 33 (3): 114–135

Gregan-Paxton J., John D.R., 1997. Consumer learning by analogy: A model of internal knowledge transfer, *Journal of Consumer Research*, 4(3): 266–284.

Greene W.H. 2000. *Econometric Analysis, 4th ed.,*Englewood Cliffs (NJ): Prentice-Hall.

Gujarati D.N. 2004. *Basic Econometrics, 4th ed.,* New York: McGraw-Hill.

Hart S.L. 1995. A natural-resource-based view of the firm, *Academy of Management Review*, 20 (4): 986-1014.

Hart S.L., Ahuja G. 1996. Does it pay to be green? An empirical examination of the relationship between emission reduction and firm performance, *Business Strategy and the Environment*, 5(1): 30-37.

Hart S.L., Milstein M.B. 1999. Global sustainability and the creative destruction of industries, *Sloan Management Review*, 41 (1):23-33.

Harrison A. 1977. Mere exposure, in L. Berkowitz (Ed.), *Advance in Experimental Social Psychology*, vol. 10: 39-83, Greenwich, CT: JAI Press.

Heckman J.J., Singer B. 1984. Econometric duration analysis, *Journal of Econometrics*, 24: 63-132.

Heller D., Levin I.P., Goransson M. 2002. Selection of strategies for narrowing choice options: antecedents and consequences, *Organizational Behaviour and Human Decision Processes*, 62 (Apr.): 113-122.

Helsen K., Schmittlein D.C. 1993. Analyzing duration times in marketing, *Marketing Science*, 12 (Fall): 395-414.

Henriques I, Sadorsky P. 1996. The role of information in coordinating environmental issues, in *Academy of Management Best Paper Proceedings*, Cincinnati, OH: 1–30.

Hitchens D., Trainor M., Clausen J., Thankappan T., de Marchi B. 2003. *Small and Medium Sized Companies in Europe – Environmental Performance Competitiveness and Management*, Heidelberg: Springer.

Hoffman A.J. 1999. Institutionalism, evolution and change: environmentalism and the US chemical industry, *Academy of Management Journal*, 42 (4): 351-371.

Hoffman A.J., Ocasio W., 2001. Not all events are attended equally: Toward a middle-range theory of industry attention to external events, *Organization Science*, 12: 415-434.

Horbach J. 2004. Determinants of ecological structural change: An empirical analysis for Germany,*RWI:Mitteilungen.Quarterly*, 54/55: 113-129.

Irwin J.R., Naylor R.W. 2009. Ethical decisions and response mode compatibility: weighting of ethical attributes in consideration sets formed by excluding versus including product alternatives, *Journal of Marketing Research*, 46 (2): 234-246.

Jaffe A., Palmer K. 1997. Environmental regulation and innovation: A panel data study, *Review of Economics and Statistics*, 79: 610–619.

Jaffe A., Stavins R.N. 1995. Dynamic incentives of environmental regulations: The effects of alternative policy instruments on technology diffusion, *Journal of Environmental Economics and Management*, 29: 543–563.

Jain D.C., Vilcassim N.J. 1991. Investigating household purchase timing decisions: A conditional hazard function approach, *Marketing Science*, 10 (Winter): 1-23.

Janssen M.A., Jager W. 2002. Stimulating diffusion of green products. Co-evolution between firms and consumers, *Journal of Evolutionary Economics*, 12: 283-306.

Jennings PD, Zandbergen PA. 1995. Ecologically sustainable organizations: an institutional approach, *Academy of Management Review* 20(4): 1015–1052.

Jiang R. J., Bansal P. 2003. Seeing the need for ISO 14001, *Journal of Management Studies*, 40 (4): 1047-1067.

Johnstone N., Glachant M., Serravalle C., Riedinger N., Scapecchi P. 2007. 'Many a slip 'twixt the cup and the lip': Direct and indirect public policy incentives to improve corporate environmental performance, in N. Johnstone (Ed.), *Environmental Policy and Corporate Behaviour*, OECD: 88-141

Kalbfleisch J.D., Prentice R.L. 1980. *The Statistical Analysis of Failure Time Data*, New York: John Wiley and Sons.

Kalyanaram G., Winter R.S. 1995. Empirical generalizations from reference price research, *Marketing Science*, 14 (3): 161-169

Kamien M.I., Schwartz N.L. 1975. Market structure and innovation: A survey, *Journal of Economic Literature*, 13(1): 1-37.

Kaplan S., Tripsas M. 2008. Thinking about technology: Applying a cognitive lens to technical change, *Research Policy*, 37: 790-805.

Kassinis G., Vafeas N. 2006. Stakeholder pressures and environmental performance, *Academy of Management Journal*, 49(1): 145-159.

Katz D., Kahn R. 1968. *Organizations: A System Approach*, Prentice-Hall: Englewood Cliffs, NJ.

Katz M., Shapiro C. 1985. Netwrok externalities, competition, and compatibility, *The American Economic Review* 75, 424-440.

Katz M., Shapiro C. 1986. Technology adoption in the presence of network externalities, *Journal of Political Economy,* 94(4): 822-841.

Kerr S., Newell R.G. 2003. Policy-induced technology adoption: evidence from the US lead phasedown, *Journal of Industrial Economics*, 51 (3): 317–343.

Khanna M., Damon L.A. 1999. EPA's voluntary 33/50 program: Impact on toxic releases and economic performance of firms, *Journal of Environmental Economics and Management,* 37: 1-25.

Khazam J., Mowery D. 1994. The commercialization of risk: strategies for the creation of oominant designs, *Research Policy*, 23: 89-102.

King A. A., Lenox M. J. 2000. Industry self-regulation without sanctions: The chemical industry's Responsible Care program, *Academy of Management Journal*, 43(4): 698-716.

King A.A., Lenox M.J. 2002. Exploring the locus of profitable pollution reduction, *Management Science*, 48: 289-299.

King A. A., Lenox M. J., Terlaak A. K. 2005. The strategic use of decentralized institutions: Exploring certification with the ISO 14001 management standard, *Academy of Management Journal*, 48(6): 1091-1106.

Klassen R.D., McLaughlin C.P. 1996. The impact of environmental management on firm performance, *Management Science*, 42: 1199-1214.

Klassen R. D., Whybark D. C. 1999. The impact of environmental technologies on manufacturing performance, *Academy of Management Journal*, 42(6): 599-615.

Klepper S. 1996. Entry, exit, growth, and innovation over the product life cycle, *American Economic Review*, 86 (3): 562-583.

Lamertz K., Baum J. 1998. The legitimacy of organizational downsizing in Canada: An analysis of explanatory media accounts, *Canadian Journal of Administrative Sciences,* 15: 93-107.

Lanjouw J.O., Mody A. 1996. Innovation and the international diffusion of environmentally responsive technology, *Research Policy*, 25: 549–571.

Lawless J.F. 1982. *Statistical Models and Methods for Lifetime Data*, New York: John Wiley and Sons.

Levin I.P., Prosansky C.M., Heller D., Brunick B.M. 2001. Prescreening of choice options in 'positive' and 'negative' decision-making tasks, *Journal of Behavioural Decision Making*, 14 (Oct.): 279-293.

Linton J.D. 2002. Forecasting the market diffusion of disruptive and discontinuous innovations, *IEEE Transactions on Engineering Management*, 49(4): 365-374.

Majumdar S.K., Marcus A.A. 2001. Rules versus discretion: The productivity consequences of flexible regulation, *Academy of Management Journal*, 44: 170-179.

Marcus A.A., Nichols M.L. 1999. On the edge: Heeding the warnings of unusual events, *Organization Science*, 10: 482-499.

McGuire J.B. Sundgren A., Scheneeweis T. 1988. Corporate social responsibility and firm financial performance, *Academy of Management Journal*, 31 (4): 854-872.

Meek G., Roberts C., Gray S. 1995. Factors influencing voluntary annual report disclosures by US, UK and continental European multinational companies, *Journal of International Business Studies*, 26 (3): 555-572.

Moreau C.P., Markman A.B., Lehmann D.R., 2001. "What is it?" Categorization flexibility and consumers' responses to really new products, *Journal of Consumer Research,* 27(4): 489–498.

Murillo-Luna J.L., Garces-Ayerbe, C., Rivera-Torres P. 2008. Why do patterns of environmental response differ? A stakeholders' pressure approach, *Strategic Management Journal*, 29: 1225-1240.

Myers S., Marquis D.G. 1969. *Successful industrial innovations. A Study of Factors Underlying Innovation in Selected Firms*, Washington DC: National Science Foundation.

Nelson R.R., Winter S.G. 1982. *An Evolutionary Theory of Economic Change*, Cambridge, MA: The Belknap Press of Harvard University Press.

Oliver C. 1991. Strategic responses to institutional processes, *Academy of Management Review,* 16: 145-179.

Orlikowski W.J., Gash D.C., 1994. Technological frames: making sense of information technology in organizations. *ACM Transactions on Information Systems*, 2 (2): 174–207.

Pedersen E. R., Neergaard P. 2006. Caveat emptor—Let the buyer beware! Environmental labeling and the limitations of “green” consumerism, *Business Strategy and the Environment*, 15: 15-29.

Peteraf M.A. 1993. The cornerstones of competitive advantage: a resource-based view. *Strategic Management Journal,* 14 (3): 179–191.

Polonsky M., Ottman J. 1998b. Stakeholders contribution to the green new product development process, *Journal of Marketing Management*, 14 (6): 533-57

Popp D. 2003. Pollution control innovations and the clean air act of 1990, *Journal of Policy Analysis and Management*, 22(4): 641-660.

Porter M.E. 1991. Towards a dynamic theory of strategy*, Strategic Management Journal*, 12 (Winter Special Issue): 95-117.

Porter M.E. 1994. The role of location in competition, *International Journal of the Economics of Business*, 1 (1): 35-40.

Porter M. E., van der Linde C. 1995. Green and competitive: Ending the stalemate, *Harvard Business Review,* 73 (5): 120-134.

Rajendran K.N., Tellis G.J. 1994. Contextual and temporal components of reference price, *Journal of Marketing*, 58 (Jan.): 22-34.

Regens J.L., Seldon B.J., Elliott E. 1997. Modelling compliance to environmental regulation: evidence from manufacturing industries, *Journal of Policy Modeling*, 19(6): 683-696.

Rivera-Camino J. 2007. Re-evaluating green marketing strategy: a stakeholder perspective, *European Journal of Marketing*, 41 (11/12): 1328 – 1358.

Rogers E.M., 1995. *Diffusion of Innovations*, 4th ed. New York: Free Press.

Rosenkopf, L., Tushman, M.L., 1993. On the Co-evolutution of organization and technology, in J. Baum and J. Sing (Eds.), *Evolutionary Dynamics of Organizations*, New York: Oxford University Press.

Rosenkopf, L., Tushman, M.L., 1998. The co-evolution of community networks and technology: Lessons from the flight simulation industry, *Industrial and Corporate Change*, 7: 311–346.

Rothenberg S. 2007. Environmental managers as institutional entrepreneurs: the influence of institutional and technical pressures on waste management, *Journal of Business Research*, 60: 749-757.

Russo M.V., Fotus P.A. 1997. A resource-based perspective on corporate environmental performance and profitability, *Academy of Management Journal*, 40(3): 534-559.

Russo M. V., Harrison N. S. 2006. Organizational design and environmental performance: Clues from the electronics industry. *Academy of Management Journal*, 48(4): 582-593.

Sahal D. 1981a. Alternative conceptions of technology, *Research Policy*, 10(1): 2-24.

Sahal D. 1981b. *Patterns of Technological Innovation*, Addison-Wesley: Readings, MA.

Salancik G., Meindl J. 1984. Corporate attributions as strategic illusions of management control, *Administrative Science Quarterly*, 29: 238-254.

Sarkis J., Cordeiro J.J. 2001. AN empirical evaluation of environmental efficiencies and firm performance: Pollution prevention versus end-of-pipe practice, *European Journal of Operational Research*, 135: 102-113.

Schilling M. 1998. Technological lockout: an integrative model of the economic and strategic factors driving technology success and failure, *Academy of Management Review*, 23(2): 267-284.

Schilling M. 2002. Technology success and failure in winner-take-all markets: The impact of learning orientation, timing, and network externalities, *Academy of Management Journal*, 45(2): 387-398.

Schmookler J. 1966. *Invention and Economic Growth*, Cambridge, Mass: Harvard University Press.

Scott W. 1994. Institutional analysis: Variance and process theory approaches, in W.Scott, J. Meyer (Eds.), *Institutional Environments and Organizations: Structural Complexity and Individualism*, California: Sage.

Scott W.R. 2005. Institutional theory: Contributing to a theoretical research program, in K.G. Smith and M.A. Hitt (Eds.), *Great Minds in Management: The process of theory development*: 460-485.l London: Oxford University Press.

Senge P.M., Carstedt G. 2001. Innovating our way to the next industrial evolution. *Sloan Management Review*, 42 (2): 24-38.

Shapiro C., Varian J. 1999. The art of standard wars, *California Management Review*, 41(2).

Sharma S., Pablo A.L., Vredenburg H. 1999. Corporate environmental responsiveness strategies: The importance of issue interpretation and organizational context, *Journal of Applied Behavioral Science*, 35(1): 87-108.

Sharma S., Vredenburg H. 1998. Proactive corporate environmental strategy and the development of competitively valuable organizational capabilities, *Strategic Management Journal*, 19 (8): 729-753.

Sharma S., Henriques I. 2005. Stakeholder influences on sustainability practices in the Canadian forest products industry, *Strategic Management Journal*, 26:159-180.

Sherer P.D., Lee K. 2002. Institutional change in large law firms: A resource dependency and institutional perspective, *Academy of Management Journal*, 43: 102-119.

Shrivastava P. 1995a. Environmental technologies and competitive advantage, *Strategic Management Journal,* 16 (Special Issue): 183-200.

Shrivastava P. 1995b. Ecocentric management for a risk society, *Academy of Management Review*, 20: 118-137.

Shrivastava P. 1995c.The role of corporations in achieving ecological sustainability, *Academy of Management Review*, 20: 936-960.

Singh J.V., Tucker D.J., and House R.J. 1984. Organizational legitimacy and the liability of newness, *Administrative Science Quarterly*, 31: 171-193.

Slater J., Angel I.T. 2004. The impact and implications of environmentally linked strategies on competitive advantage: A study of Malaysian companies, *Journal of Business Research*, 47: 75-89.

Sood A., Tellis G.J. 2005. Technological evolution and radical innovation, *Journal of Marketing*, 69 (July): 152-168.

Srinivasan R., Lilien G.L., Rangaswamy A. 2006. The emergence of dominant designs, *Journal of Marketing*, 70(April): 1-17.

Starik M., Rands G.P. 1995. Weaving an integrated web: Multilevel and multisystem perspectives of ecologically sustainable organizations, *Academy of Management Review*, 20(4): 908-935.

Stabell C.B., Fjledstad O.D. 1998. Configuring Value for competitive advantage: On chains, shops and networks, *Strategic Management Journal*, 19 (5): 413-437.

Stremersch S., Tellis G.J. 2004. Understanding and managing international growth of new product, *International Journal of Research in Marketing*, 21(4): 421-438.

Stremersch S., Tellis G.J., Franses P.H., Binken J.L.G. 2007. Indirect network effects in new product growth, *Journal of Marketing*, 71 (July): 52-74.

Suarez F. 2004. Battles for technological dominance: an integrative framework, *Research Policy*, 33: 271-286.

Suarez F., Utterback J. 1995. Dominant design and the survival of firms, *Strategic Management Journal,* 16: 415-430.

Sutton J. 1997. Gibrat's legacy, *Journal of Economic Literature*, 35(1): 40-59.

Sutton J. 1991. *Sunk Costs and Market Structure*, Cambridge, Massachusetts: MIT Press.

Teece D. 1986. Profiting from technological innovation: implications for integration, collaboration, licensing, and public policy, *Research Policy*, 15: 285-305.

Teece D.J., Pisano G., and Shuen A. 1997. Dynamic capabilities and strategic management, S*trategic Management Journal,* 18 (7): 509–533.

Tellis G.J., Golder P.N. 1996. First to market, first to fail? Real causes of enduring market leadership, *Sloan Management Review*, 37 (2): 65-75.

Tellis G.J., Stremersch S., Yin E. 2003. The international takeoff of new products: The role of economics, culture, and country innovativeness, *Marketing Science*, 22(2): 188-208.

Tripsas M., 2008. Customer preference discontinuities: a trigger for radical technological change. *Managerial and Decision Economics*, 29: 79–97.

Tripsas M., Gavetti G. 2000. Capabilities, cognition, and inertia: evidence from digital imaging, *Strategic Management Journal*, 21 (10/11): 1147-1161.

Turban D.B., Greening D.W. 1997. Corporate social performance and organizational attractiveness to prospective employees, *Academy of Management Journal,* 40: 658-672

Tushman M.L., Anderson P. 1986. Technological discontinuities and organizational environments, *Administrative Science Quarterly*, 31(3): 439-465.

Tushman M.L., Rosenkopf L. 1992. Organizational determinants of technological change: Toward a sociology of technological evolution, *Research in Organizational behaviour*, 14: 311-347.

Urban G.L., Von Hippel E. 1988. Lead user analysis for the development of new industrial products, *Management Science*, 34(5): 569-582.

US Departmetn of Energy. 2009. *CFL Market Profile*, www.energystar.gov/ia/products/downloads/CFL_Market_Profile.pdf.

Utterback J.M. 1974. Innovation in industry and the diffusion of technology, *Science*, 1983 (Feb. 15th): 658-662.

Utterback J.M. 1994. *Mastering the Dynamics of Innovation*. Boston: Harvard Business School Press.

Utterback J.M. and Abernathy W. 1975. A dynamic model of product and process innovation, *Omega*, 3: 639-656.

Utterback, J. M. and Suarez, F. F. 1993. Innovation, Competition, and Industry Structure, *Research Policy*, Vol. 22, 1-21

Van de Ven A.H., Garud R. 1993. The co-evolution of technical and institutional events in the development of an innovation, in J. Baum and J. Sing (Eds.), *Evolutionary Dynamics of Organizations*, New York: Oxford University Press.

Van de Ven A.H., Huber G.P. 1990. Longitudinal field research methods for studying processes of organizational change, *Organization Science*, 1 (3): 213-219.

Vasanthakumar B. 1993. Green marketing begins with green design, *Journal of Business & Industrial Marketing*, (8) 4: 26-31.

Vogel D.J. 2005. Is There a Market for Virtue? The Business case for corporate social responsibility, *California Management Review*, 47 (4): 19-45.

Von Hippel E., 1986. Lead users: a source of novel product concepts, *Management Science,* 32(7): 791–805.

Von Hippel E.1988. *The Sources of Innovation*, Oxford University Press.

Wade J. 1995. Dynamics of organizational communities and technological bandwagons: An empirical investigation of community evolution in the microprocessor market, *Strategic Management Journal*, 16(5): 111-133.

Wade-Benzoni K.A., Hoffman A.J., Thompson L.L., Moore D.A., Gillespie J.J., and Bazerman M. H. 2002. Barriers to resolution in ideologically based negotiations: The role of values and institutions, *Academy of Management Review*, 27 (1): 41-57.

Walsh S.T. 2002. Differentiating marketing strategies for disruptive technologies, *IEEE Transactions on Engineering Management*, 49(4): 341-351.

Walz R. 1999. Productivity effects of technology diffusion induced by an energy tax, *Energy and Environment*,10 (2):169-180.

WCED. 1987. *Our Common Future*. Oxford University Press: Oxford.

Wernerfelt B. 1984. A resource based view of the firm, *Strategic Management Journal, 5:* 171-180.

Wood D.J. 1991. Corporate social performance revisited, *Academy of Management Review*, 16 (4):691-718.

Wooldridge J.M. 1999. *Econometric Analysis of Cross Section and Panel Data*, Cambridge (Mass.): MIT Press.

Zuckerman E.W. 1999. The categorical imperative: Securities analysts and the illegitimacy discount, *American Journal of Sociology*, 104: 1398-1438.