Effects of Environmental Regulation on Innovation Decisions

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Boston College Electronic Thesis or Dissertation, 2010

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Effects of Environmental Regulation on Innovation Decisions

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April 30, 2010
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1 Statement of Topic

Since Porter first proposed in his 1991 paper entitled *America’s Green Strategy* that environmental regulation would lead to innovation, and thus lead to a competitive advantage for businesses, there has been much debate over whether this relationship holds true. Up until this point there has been research, both theoretical and empirical, to support both sides of the argument with important consequences for policy makers. In the face of serious global environmental problems, including unprecedented climate change and a global economy that has not yet turned its attention to addressing these issues, political leaders are struggling to draft policy that will successfully encourage the private sector to reduce its environmental impact without damaging profits or restricting growth.

This paper will review prior research to support the notion that innovation does in fact lead to a competitive advantage for business, and that this competitive advantage is translated into increased profitability and productivity. Though the body of work reviewed here will by no means unequivocally prove that this relationship always holds true in real-world markets, it will provide a convincing argument that fostering innovation will likely have positive economic effects. Building off this assumption, this paper will then focus specifically on examining the relationship between environmental regulation and innovation in more detail. This paper looks to answer the question: Under what conditions will environmental regulation cause firms to begin choosing to innovate technologically rather than simply to meet regulation with compliance? This question will be answered in two ways:

First, this paper will present various case studies focusing on companies that have met environmental regulation with innovation. Using these case studies, a framework will be developed which identifies conditions under which environmental regulation will tend to foster innovation. For the purposes of this paper, the term innovation can be seen as synonymous with research and development (R&D), since R&D is the principal method that a firm uses to achieve proprietary innovation.

Second, in light of this framework a mechanism will be identified in order to model the successful innovation that the firms discussed in this paper have enjoyed. Drawing from examples in the case studies, the model will look to specifically analyze situations in which firms are made better off by their innovation decisions. This analysis will consider the factors that influence a firm’s decision to innovate in the face of regulation, rather than to merely comply with environmental regulation by implementing so-called “end-of-pipe” solutions, as well as provide insight as to why these firms would not choose to undertake such projects without the help of environmental regulation.

Together with the framework, this model will provide a more complete understanding of the conditions under which environmental regulation can successfully induce innovation in firms. By fostering innovation, such environmental regulation will not merely have a reduced chance of impairing firm performance, but more importantly will have an increased chance of actually making firms more profitable and more competitive.
2 Background on the Porter Hypothesis

2.1 Introduction

The so-called Porter Hypothesis can be more completely summed up as follows:

“ Appropriately planned environmental regulations will stimulate technological innovation, leading to reductions in expenses and improvements in quality. As a result, domestic businesses may attain a superior competitive position in the international marketplace, and industrial productivity may increase as well” (Friedman 2008, p. 272).

As stated, there are in fact two distinct relationships that are proposed in the Porter Hypothesis: (1) the positive relationship between environmental regulation and innovation, and (2) the positive relationship between innovation and competitive position/industrial productivity. Therefore, it is necessary to understand the factors that influence both of these relationships in order to fully understand how Porter’s Hypothesis can properly inform environmental policy.

2.2 The Relationship between Environmental Regulation and Innovation

Though Porter does not explore the relationship between regulation and innovation in depth, he does propose various ways in which environmental regulation could theoretically influence innovation decisions. He proposes that environmental regulations can:

1. “Signal companies about resource inefficiencies & potential technological improvements.”
2. “Reduce uncertainty that investments to address the environment will be valuable.”
3. “Overcome organizational inertia, foster creative thinking and mitigate agency problems.”

Given the relative lack research/analysis that is available regarding the regulation-innovation relationship, there is much insight to be gained into the practicality of using the Porter Hypothesis to influence policy making by studying innovation decisions. Furthermore, if the relationship between environmental regulation and innovation decision can be better understood then the Porter Hypothesis will gather new strength in environmental regulation debates moving forward.

2.3 The Relationship between Innovation and Competitive Advantage/Industrial Productivity

In the context of Porter’s original research, the relationship between innovation and competitive advantage can be seen as the starting point of the Porter Hypothesis. In coming up with this hypothesis he worked backwards, beginning with a measurable observation and then proposing a theoretical mechanism that would explain how these results could be achieved. In his book The Competitive Advantage of Nations Porter notices that nations with the most rigorous environmental requirements often lead in
exports of affected products (Porter 1990). One of his most powerful examples is the observation that both Japan and Germany, countries who have enacted stricter environmental regulations than the United States, had surpassed the U.S. in GNP growth and rates of productivity growth during periods of more stringent regulation (Porter 1991).

Porter & van der Linde (1995) termed the benefits resulting from environmental regulation innovation offsets, and noted that such offsets can occur in products (innovation creates better performing products) and in processes (innovation can cause higher resource productivity). In response to this, there has been much additional research to verify or refute whether this relationship holds true. Empirical studies have attempted to quantify and measure the competitive advantage or environmental profit that firms can achieve through innovation. However, this research spends little time exploring the relationship between regulation and innovation itself.

3 Literature Review

3.1 Introduction

The current literature focusing on the debate surrounding the Porter Hypothesis takes the form of both empirical analysis and formal models, focusing on the relationship between innovation and competitive advantage. The literature attempts to shed light on this relationship by determining whether firms gain a competitive advantage through innovation and by attempting to measure or quantify any environmental profit that firms gain by innovating. Although this paper will not attempt to follow in the footsteps of this literature, it is nevertheless a worthwhile exercise to review the current body of work in order to provide the proper context for this paper.

In the case of empirical studies, a statistical approach is taken to either confirm or deny the Porter Hypothesis based on data collected concerning the competitiveness of firms after facing environmental regulation. Because these studies focus on analyzing the relationship between innovation and competitive advantage, only studies which support the Porter Hypothesis are presented here. Their purpose is to lend credence to the assumption that innovation will likely lead to a competitive advantage for firms, so that this paper may focus on exploring the relationship between regulation and innovation in more detail.

In the case of formal models, theoretical knowledge about the Porter Hypothesis is explored using models to explain the mechanisms by which his hypothesis is presumed to operate. These models serve either to support or refute the Porter Hypothesis, as well as serve to qualify certain assumptions or mechanisms of how the model functions. In this review, models serving both purposes will be considered as important sources of analysis on the Porter Hypothesis as a whole, as well as important building blocks for a similar model to be developed that will better explain the relationship between environmental regulation and innovation decisions.
Because this paper will attempt to provide a new model aimed at understanding the relationship between environmental regulation and innovation (specifically R&D), there is special attention paid to past research in this area. This paper will not only summarize past findings, but also will identify gaps in the literature and explain how this paper will differ in its approach to understanding the relationship between regulation and innovation.

3.2 Empirical Analysis of the Porter Hypothesis

Though Porter & van der Linde (1995) did not rely on empirical analysis in their original discussion of the Porter Hypothesis, empirical results are nevertheless an important source of information for the debate moving forward. Namely, empirical evidence has been a critical way of linking environmental regulation to competitive advantage, however that may be defined, and measuring the costs and/or benefits that firms have faced as a result of regulation. Therefore, consideration of past empirical studies that support the Porter Hypothesis is an important step in confirming the practical results of the hypothesis as well as in shedding light on concepts that require more study moving forward.

Jaffe et al. (1995) review 16 empirical studies on the effects of environmental regulation on competitiveness in manufacturing firms, particularly in the U.S. In their analysis, they consider studies that use many different measures of competitiveness, including net exports, overall trade flows, and plant location decisions. Jaffe et al. (1995) are able to conclude that “there is relatively little evidence to support the hypothesis that environmental regulations have had a large adverse effect on competitiveness, however that elusive term is defined” (Jaffe et al. 1995, p. 157). By concluding that firms are not as adversely affected as previously expected, this study lends support to the Porter Hypothesis and indicates that there is a mechanism through which firms improve their performance when faced with environmental regulation.

Similarly, Mulatu et al. (2001) provide meta-analysis of 13 studies that analyze the effect of environmental regulation on international trade. Overall, they conclude “that the empirical literature does not strongly support the hypothesis, that the effect of environmental regulation on competitiveness is negative” (Mulatu et al. 2001, p. 22). Again this study lends support to the Porter Hypothesis, and by further examining the effects of environmental regulation in international markets Mulatu et al. (2001) explore a crucial component of Porter’s original research.

Murty & Kumar (2003) measure the productive efficiency of 92 firms in water-polluting industries in India. By creating indices to measure a firm’s level of compliance as well as their level of conservation, the study then compares these levels against the efficiency of the firms in order to explore the relationship between environmental regulation and technical inefficiency. Murty and Kumar (2003) find that a firm’s higher level of compliance as well as higher level of conservation lead to lower technical inefficiency of the firm, which again supports the Porter Hypothesis.
3.3 Theoretical Analysis of the Porter Hypothesis

There are several theoretical studies that cast doubt on whether the Porter Hypothesis can be used to effectively increase competitive advantage and industrial productivity. For example, Lankoski (2000) analyzes the effects of regulation on vertical product differentiation within a duopoly. In Lankoski’s model, firms are allowed to supply products at different levels of environmental performance, with different costs and benefits assigned to each, and then face either Bertrand or Cournot competition, deciding the price or quantity at which to supply. The paper concludes that “firms always choose to provide distinct levels of environmental performance at the optimum” (Lankoski 2000, p. 29), meaning that the environmental performance supplied by the firms on their own may not be socially optimal and would thus inspire regulation. Lankoski (2000) interprets these results to mean that the link between regulation & competitiveness is not uniform, and that the validity of Porter Hypothesis depends heavily on market dynamics that may be different across industries.

Simpson & Bradford III (1996) provide even stronger theoretical evidence that the relationship between innovation and competitive advantage does not hold. Their model analyzes domestic and foreign firms competing in Cournot duopoly, in which the domestic firm’s government attempts to induce a competitive advantage for the domestic firm by instituting an effluent tax. The firms’ supply decisions are calculated, and Simpson & Bradford III (1996) conclude that it is very difficult to impart parameters on the model for which an effluent tax imposed by the domestic government makes the domestic firm more competitive.

However, Sinclair-Desgagne (1999) proposes that the underlying theory of the Porter Hypothesis is consistent because inefficiencies in firms are revealed under stringent regulations. Furthermore, there are many formal models to support this claim, as well as to support the relationship between innovation and competitive advantage proposed by the Porter Hypothesis.

Xepapadeas & de Zeeuw (1999) show that downsizing and modernization in firms subject to stringent environmental regulations increases profitability. As a result, they are able to conclude that environmental regulation has a positive effect on the marginal change of profitability and environmental performance simultaneously. Furthermore, Mohr (2002) expands on this study by additionally considering external economies of scale in production, allowing productivity to depend on the cumulative experience with a technology. Mohr (2002) again finds that policy can simultaneously increase productivity and reduce externalities, and concludes that “Porter’s Hypothesis is a plausible outcome if one allows for the possibility of technological change with external economies of scale” (Mohr 2002, p. 164).

Finally, Alpay (2001) builds on the Simpson & Bradford III model previously mentioned in order to analyze the comparative effects of the government regulation using a tradable emissions permit systems versus a straight effluent tax. Alpay (2001) finds that in this model it is much easier for firms to be profitable in the face of regulation, and thus gain a
competitive advantage in the international marketplace, because of revenues realized from traded permits. It should be noted, however, that although this finding supports the Porter Hypothesis, it also introduces another level of complication to the analysis by tying firm performance to the dynamics of a permit market system.

3.4 The Relationship Between Regulation and R&D

There is much previous work exploring the relationship between environmental regulation and R&D. The benefit of exploring this literature is twofold: (1) the results of these studies lend support to the theory behind the Porter Hypothesis and thus provide a strong foundation for the model in this paper, and (2) analyzing the mechanism outlined in these studies will provide context and guidance for the mechanism presented later in this paper.

Greaker & Pade (2009) present a study that analyzes the level of carbon dioxide emissions taxes. In their study, Greaker & Pade (2009) acknowledge that setting a higher emissions tax today can be a beneficial form of environmental regulation, through its influence of innovation, if we have technological change driven by R&D rather than pure exogenous technological change. Given this assumption they develop simulation criteria for understanding when setting a high emissions tax today is most beneficial. They find that “these circumstances are (a) ‘a standing on shoulders’ type of knowledge spillover and/or (b) weak patent protection” (Greaker & Pade 2009, p. 351). Their study clearly establishes the beneficial link between environmental regulation and innovation, and even goes on to clearly identify certain conditions that must be satisfied in order for this relationship to hold. Building off of this established connection, this paper hopes to examine specifically how R&D decisions at the firm level are affected by environmental regulation.

Ambec & Barla (2001) provide a theoretical foundation of the Porter Hypothesis by considering a model in which a division manager implements and manages a new production plant, which begins with an initial investment in R&D under the direction of the firm’s larger hierarchical authority. In this study, they consider the outcomes of the firm’s project in two scenarios, one without regulation and one with regulation. Through a model of renegotiation, Ambec & Barla (2001) show that environmental regulation applies external pressure that is able overcome organizational inertia in order to enhance pollution-reducing innovation and increase a firm’s private benefit. This study provides a good preliminary insight into how environmental regulation can influence a firm’s R&D decisions. However, the mechanism through which this regulation influence firm behavior (renegotiation) is not in line with the major findings of the case studies to be presented in Section 4. Therefore, though Ambec & Barla’s study serves as an encouraging example to support the notion that there is an important link between environmental regulation and innovation, this paper will look to identify a different mechanism through which the Porter Hypothesis operates.

Popp (2005) outlines a mechanism that is most consistent with the case studies to be presented later in this paper. His study attempts to model the conclusions of the Porter
Hypothesis in a way that is consistent with neoclassical economic principals by considering the influence that environmental regulation can have on the uncertainty inherent to R&D projects. Popp (2005) calibrates a model of R&D that allows for a positive expected value of the project only when regulation is imposed. Using this model it is found that, “between 8 and 24 percent of simulation runs result in R&D that increases profits with regulation to levels greater than profits without R&D” (Popp 2005, p. 8). This study clearly identifies uncertainty in R&D as a mechanism by which firms can benefit from environmental regulation. However, the results of this study are limited to the decisions of only one firm. Therefore, in order to more completely understand this mechanism it will be necessary to consider the interactions among multiple firms who will be faced with environmental regulation and decisions regarding uncertain R&D projects.

3.5 Summary

In analyzing the literature above it is clear that, although there is much previous work that supports the Porter Hypothesis, a greater understanding of the mechanisms that drive the benefits of environmental regulation is needed in order to affect meaningful change in regard to policy decisions. As the following case studies will show, there are many success stories resulting from environmental regulation in the past. Using these case studies to identify specific mechanisms for the beneficial effects of environmental regulation will fill in the gaps of previous work concerning the Porter Hypothesis and should provide a means to develop a more consistent relationship between regulation and innovation in the future.

4 Case Studies

4.1 Introduction

The case studies presented here serve as examples of how various businesses have met environmental regulation with technological innovations. The following examples will explore cases in which the decision to innovate has met with great success, as evidenced by greater profits or cost reductions, as well as a case in which regulation did not lead to enhanced firm performance. The purpose of exploring both of these scenarios is to gain a more complete understanding of the complex interaction between regulation and innovation decisions, and thus be able to identify a mechanism through which regulation is likely to be successful in benefiting a firm. Each case study will provide historical context for both the affected firm and the imposed regulation, detail the environmental regulation imposed and the firms innovation decision, describe the results of this innovation decision, and provide analysis of why this regulation was or was not successful in benefiting the firm. From here the following section will synthesize these analyses as well as identify and develop a mechanism that accurately reflects the success of these firms, which will serve to guide the model present in Section 5.
4.2 GE Transportation

Friedman (2008) provides insight into how GE Transportation, maker of locomotives located in Erie, PA, is responsible for the city’s trade surplus with China, Mexico, and Brazil. This trade surplus is a result of the company’s Evolution Series diesel locomotive (EVO), which sell at approximately $4 million a piece. According to Friedman (2008) GE sells this top of the line locomotive to railroad companies worldwide, including Mexico, Brazil, Australia and Kazakhstan, and will have exported 300 to China by the end of 2009. Even though these engines are more expensive than ones produced in the countries to which they are being exported, the EVO is coveted for its fuel efficiency and reliability, characteristics that are a result of engine innovations that GE Transportation undertook in response to stricter emissions standards by the EPA in 2004.

The EPA has a long history of regulating the emissions of locomotives and other transportation vehicles. In 2004 the EPA issued new Tier II standards, which required big reductions in both particulates and nitrogen oxide. GE’s traditional approach to deal with this sort of regulation was to meet regulatory compliance by tweaking a engine that already met the current standards, and then deal with a tradeoff in variables like fuel efficiency, power, or reliability. But in this case, GE’s chairman, Jeffery Immelt, instead encouraged the engineers to start from scratch and build an entirely new engine; in other words, he decided to innovate.

The result was a focus on increasing reliability, lowering emissions, and increasing fuel efficiency all at the same time with a new design and new materials. Accordingly, GE Transportation was successful in creating the most energy efficient locomotive on the market, getting the best fuel mileage per ton pulled, and in creating the locomotive with the lowest emissions of CO₂, traditional soot particles, and nitrogen oxide. Friedman (2008) reports that the EVO is 5% more fuel efficient than the old model, which translates into a savings of approximately 300,000 gallons of fuel over its lifetime. GE Transportation’s President and CEO, John Dineen, admits, “The EPA can be credited with instigating the need to drive new technologies into these locomotives” (Friedman 2008, p. 271).

Jarratt et al. (2003) puts GE success into context with their examination of how environmental regulation has become a driver of the design process across the fast paced and competitive diesel engine manufacturing industry. Due to the steady increase in emissions standards, they have analyzed how the industry has reacted to meet regulatory requirements and have concluded, “Although each successive wave of regulation looks exceptionally hard to meet, increased levels of innovation within the industry are ensuring that solutions are found. Diesel engine manufacturers have adapted and are now used to operating in a legislative environment” (Jarratt et al. 2003, p. 9).

Given that there is an industry wide recognition of the need to innovate as a result of increasingly stringent environmental regulation, how then was GE able to achieve such a level of differentiation and recognize such success? The success of GE’s R&D project is perhaps more serendipitous than it may at first seem. Obviously, redesigning a
locomotive engine from scratch was a significant investment for GE Transportation and a significant risk. At the time there was no guarantee to the company that they would actually benefit from putting in the effort to create a more fuel-efficient locomotive. Dineen remarked, “We were not sure the Chinese would be interested in lower emissions, but they are” (Friedman 2008, p. 271). In this case, GE Transportation benefited from fact that carbon emissions became an issue for many countries beyond the U.S. According to Friedman (2008) in 2008 China overtook the U.S. as the world’s leading carbon emitter, and as such China’s government owned railroads became interested in buying more fuel-efficient locomotives. GE Transportation even saw very quick adoption rates in international markets that do not have government mandates. This leads to the conclusion that environmental regulation can lead to successful innovation if this same regulation is adopted or favored by other countries as well. Under these circumstances, a new market is created for products that meet the new levels of environmental regulation and the domestic firm benefits by achieving a first mover advantage.

### 4.3 HP

Nidumolu et al. (2009) recount how Hewlett-Packard has consistently demonstrated an approach of meeting regulation with innovation by viewing compliance as a business opportunity. By better understanding the context in which HP views regulation as an economic opportunity, we can better understand general trends and characteristics that will lead to positive effects of environmental regulation.

In the 1990’s HP realized that, because the lead it was using in solders is toxic, it was very likely that governments would eventually ban lead in solders. In the following years HP developed a solder using an amalgam of tin, silver, and copper, and as a result was able to comply with the European Union’s Restriction of Hazardous Substance (RoHS) directive, which regulates the use of lead in electronics product, as soon as it took effect in 2006, lending the company a significant first mover advantage. In a separate study, Eveloy et al. (2005) report, “The cost of implementing the RoHS directive in the EU has been estimated to be US$ 20Bn. Intel Corporation’s efforts to remove lead from its chips have been estimated to cost the company over US$ 100 million so far” (Eveloy et al. 2005, p. 884). So while other companies struggled to switch over to new technologies as a result of the ban on lead, HP’s use of innovation allowed it to enjoy a smooth transition at a greatly reduced cost compared to its rivals.

In 2002 HP learned that the Europe’s Waste Electrical and Electronic Equipment (WEEE) regulation would begin requiring hardware manufactures to pay for the cost of recycling products. Knowing that the government sponsored recycling programs would be expensive, HP instead partnered with three other hardware manufacturers (Sony, Braun, and Electrolux) to create a private European Recycling Platform. According to Nidumolu et al. (2009), in 2007 the platform worked with over 1,000 companies in 30 countries to recycle approximately 20% of the material covered by the WEEE Directive. Furthermore, because of the platform’s scale it is able to charge almost 55% lower prices that its competitors and has saved HP $100 million from 2003 to 2007.
Finally, HP’s continued efforts to be on the forefront of innovation in the face of regulation has also allowed the company to become allies with regulators and shape many environmental regulations in Europe. For example, in 2001 the European Union mandated that hardware manufacturers could no longer use hexavalent chromium as an anticorrosion coating their products. HP, like many other manufacturers, felt the industry needed more time to develop alternatives, and was able to convince regulators to push back the ban one year (Nidumolu et al. 2002). HP used this time to complete testing of organic and trivalent chromium coatings, as well as transfer this technology to more than one of its vendors. Nidumolu et al. (2009) reports that as a result, vendors competed to supply the new coatings, which in turn lowered HP’s costs.

HP’s case demonstrates that there must be strong economic incentives in order for regulation to foster successful innovation. HP’s consistent success with innovation hinges on their ability to monetize their investments, mostly through cost cutting measures. Therefore identifying environmental regulations that will encourage cost reductions, either through waste reduction or reducing the cost of inputs, will have a greater potential to foster innovation. It is also important to note that, as in the case of GE Transportation, there was a strong international component to HP’s success with innovation. This link reinforces the notion that in order for regulation to successfully foster innovation a similar level of standards must be present across countries.

4.4 The Honda Civic

The 1970 Federal Clean Air Act in the United States required a 90% reduction in automobile emissions. Prior to 1969, end-of-pipe technologies, like catalytic converters, were thought to be the only means by which car companies could comply with emissions requirements. Catalytic converters represented an additional cost to automakers and therefore caused Detroit firms to lobby against the new regulation due to fears of this regulation decreasing their competitiveness. By ignoring possible innovations in technology, Detroit automakers grossly overestimated the cost of compliance as well as claimed that the new regulation made it impossible to meet both the emissions standards and the fuel economy standards that the government was imposing.

Hwang & Peak (2006) detail how Honda was able to overcome this challenge with innovation. Honda pursued other methods of emissions reduction, and encouraged by its founder, Soichiro Honda, the company attempted to clean up the exhaust gases inside of the engine itself without relying on catalytic converters. This innovation led Honda engineers to utilize existing technologies in a way that produce a cleaner burning engine. The “Compound Vortex Controlled Combustion” (CVCC) engine that they created had a small pre-burn chamber before the cylinders, and this pre-burning resulted in more impurities being removed before they reached the tailpipe. Hwang & Peak (2006) report that as a result, Honda was able to comply with the 1970’s regulation without the addition of catalytic converters. Furthermore, the innovation proved to be additionally beneficial to Honda too, as each of the Detroit auto manufacturers licensed the technology from Honda in 1973.
Interestingly, during this same period other automakers were also pursuing some R&D projects of their own. However, their innovation was focused around end-of-pipe technologies, and for the major Detroit manufacturers their R&D efforts were only half-hearted. Gerard & Lave (2004) report that GM pursued the development of converter technology merely as a means to improve the company’s image in reaction to bad publicity in the 1960’s. Similarly, they report that Ford’s R&D undertaking was little more than a front to avoid falling behind GM. Finally, Gerard & Lave (2004) also point out that Chrysler in the meantime made no real effort to pursue any R&D in response to the threat of the 1970 Clean Air Act. Yet when Chrylser failed to secure new technology from external suppliers, and failed to meet compliance with the new standards, it found itself at a huge disadvantage. As a result “the company was performing very poorly, losing unprecedented sums of money, and hurtling toward a massive government bailout by the end of the decade” (Gerard & Lave 2004, p. 770). In all three cases, the lack of commitment to meaningful R&D projects to address new environmental regulation represents a major step backward in competitive advantage relative to Honda.

Here it is interesting to note that the company that benefited most from domestic environmental regulation was, in fact, a foreign company competing in this market. By recognizing the opportunity for innovation, Honda gained a first mover advantage in cleaner engine technologies, which became a valuable innovation in the face of increasing emissions requirements in the United States. Honda benefited not only by reducing its own costs of compliance, but also by receiving revenue from the licensing of its technology to other competitors who had pursued failing R&D projects or none at all. Although this case study illustrates very well how regulation can induce innovation in an industry, it also illuminates the complicated dynamics that regulations have on international markets. It can be argued that the environmental regulation imposed by the EPA by the 1970 Clean Air Act indeed did have adverse effects on the domestic automobile industry, because it allowed a foreign competitor to gain a competitive advantage. In such a market, where international competitors already exist, it may be very difficult for the Porter Hypothesis to hold true given that foreign firms have equal opportunity to innovate in the face of regulation. Therefore, in order to craft regulation in such a way as to benefit domestic firms a mutual relationship must be developed between regulators and industry, in which industry is receptive and works constructively with regulators to address their needs and concerns.

4.5 Peugeot SA

Though all cars in the U.S. eventually had been outfitted with 3-way catalytic converters as of 1981, similar regulation in Europe developed much more slowly. Sinclair-Desgagne (1999) details how during this time Peugeot SA, a French carmaker, (as well as Ford Europe) pursued an alternative to the catalytic converter in what they called a “lean-burn” engine. Similar to the case of Honda in the face of the 1970s Clean Air Act, Peugeot SA was attempting to meet increasing emissions standards not with end-of-pipe technologies, but instead with innovation at the source of pollution. The new design it was pursuing allowed engines to run on higher fuel/air ratios, thus reducing carbon and nitrogen oxide emissions.
Sinclair-Desgagne (1999) further explains that at the time that Peugeot SA was pursuing this innovation, the French government was behind other European countries in its emissions standards. For example, at this time Germany, an important trade partner, had already adopted the catalytic converter standard. As a result, the French government faced increasing pressure from environmental lobbies and other European countries to adopt stricter standards on car emissions. However, the French Government faced a tradeoff because Peugeot SA already had a head start on pursuing the development of a better technology, but due to Peugeot SA’s having just completed a difficult turnaround it would not be able to continue pursuing this development if forced to comply with stricter regulations. Because Peugeot SA was one of France’s major employers, the government delayed compliance with many of the European standards for years, but was eventually forced enact stricter emissions standards. According to Sinclair-Desgange (1999) this regulation in turn killed Peugot SA’s development efforts for the lean-burn engine, as the company no longer had an incentive to pursue this technological innovation when forced to utilize catalytic converters.

In this example we see regulation having almost the exact opposite effect on innovation that the 1970’s Clean Air Act had on the Honda Civic. In the case of Peugeot SA, the regulation that the firm faced served to discourage the pursuit of technological innovation because the regulation mandated the implementation of end-of-pipe technologies that were in direct opposition to the goals of innovation. Therefore, it can be said that any regulation that hopes to encourage technological innovation must focus on broad based issues in pollution reduction, and not mandate specific technologies that firms must implement in pursuing compliance with these standards. Finally, the fact that the French government consistently delayed environmental regulation and did not send a clear message of when stricter standards would be implemented likely resulted in Peugeot SA’s delay in completing its research for the lean-burn engine. If Peugeot SA had been given a clearer timeline of when to expect stricter environmental regulation then the firm could have better planned its innovation efforts. Here, delay in regulation produced the opposite of a first mover advantage for Peugeot SA, and therefore it is suggested that the timing of environmental regulation relative to other countries has a profound importance on that regulation’s ability to foster successful technological innovation.

4.6 Summary

From these case studies we can identify the following five characteristic that environmental regulation should have in order to successfully encourage innovations in firms:

1. The regulation must not mandate specific “end-of-pipe” solutions, but rather should allow for individual firms to decide how to achieve compliance.

2. The regulation creates a market for new products that satisfy the need of all firms within an industry to meet more stringent levels of compliance.

3. The regulation inspires technological innovations that will have the ability to cut costs for firms in the future.
(4) The regulation provides the opportunity for increased revenues from licensing of new technologies used to meet compliance.

(5) The regulation reduces the uncertainty of R&D investments by providing a clear timeline of when firms will be expected to meet the new levels of compliance.

5 Mechanism

5.1 Introduction

These case studies show that there is clear anecdotal evidence to support the notion that environmental regulation can successfully induce innovation in firms and lead to economic benefits. The purpose of this section is to identify a mechanism through which environmental regulation provides this incentive and then to analyze firm behavior given this mechanism.

In all the cases mentioned above, environmental regulation can be seen to provide economic incentives to affected firms under the condition that the regulation reduces the uncertainty of R&D projects; that is to say, the affected firms were able to perceive the ability to receive a return on their investment in innovative technologies. This reduction in uncertainty allowed firms to undertake R&D projects that benefited them economically but that they might not have undertaken without regulation.

5.2 Hypothesis

The economic incentives mentioned above appear as investments in R&D projects, which when successful provide the firm with a competitive advantage. The success of an R&D project is determined by its ability to provide an increase in profitability that will compensate for the cost of undertaking the project. Therefore, in light of environmental regulation a successful R&D project can be achieved in two ways:

(1) The project will result in a reduction in marginal cost for the firm. By lowering its marginal cost, a firm can achieve higher market share and thus higher profits. Furthermore, if the innovation that results from the R&D project is truly revolutionary, the firm may even enjoy increased revenue from the licensing of this technology to competitors.

(2) The regulation will create public awareness about the environmental impacts of the firm’s operations. The public awareness can be met with consumers’ increased demand for “green” technologies, as they perceive a greater benefit in these products over old, dirtier ones. This outward shift in the demand curve would allow firms supplying cleaner products to charge a higher price for their products, and thus there would be a clear benefit for undertaking an R&D project that would satisfy this demand.
The following model will focus on examining the first scenario from above, considering marginal cost reductions and license fees. However, it is clear from the case studies presented above that there are many complicated market dynamics that influence the success of an R&D project. It is therefore necessary to consider the situation in which more than one firm may be induced to undertake R&D initiatives when faced with regulation. In this scenario, firms must not only consider the uncertainty of their own proposed R&D projects but also must consider the possibility of their competitors achieving successful R&D projects as well.

This consideration can lead to an R&D race, in which several firms compete to develop innovative technologies. There will be two phases of this R&D race: (1) One firm will develop a successful technology, and (2) this technology will then be shared across firms in the industry. The first firm to realize a successful R&D project will initially be the only one to realize the benefits of increased profits. But as the technology is shared among firms, this R&D race will ultimately benefit the entire industry by allowing all firms to benefit from the new technology. In the end all firms are better off, and enjoy lower costs and higher profits than before regulation. However, there is a strong incentive to be the first company to develop this new technology in order to receive a competitive advantage over other firms before the industry catches up. This competition will increase the likelihood of a firm completing a successful R&D project when faced with regulation, thus supporting and strengthening the connections between regulation and innovation.

Furthermore, a major question that remains to be answered by this analysis is why environmental regulation is necessary in order to spur innovation decisions. That is to say, if these R&D projects to develop new cost-saving technologies will lead to increased profitably for firms why would they not choose to invest in these projects anyway? An appropriate answer to this question is central in developing support for the Porter Hypothesis, and as such this paper will focus in particular on parameters and cost structures that reflect price competition scenarios in which companies initially have equilibrium strategies to not invest in innovation but are then subsequently incentivized to do so by environmental regulation.

5.3 Price Competition and the Innovation Decision

In order to analyze the economic impact of environmental regulation on firms a simple price competition game will be simulated between two firms that sell homogeneous products. Dixit and Skeath (2004) provide a model for price competition between two such firms, in which Firm 1 and Firm 2 must simultaneously choose a price (P₁ and P₂, respectively) at which to offer their products with the goal of profit maximization. Here, price is considered to be a continuous variable and therefore can take on any value within an infinite range. In this model a firm’s pricing decision affects profit through shifting demand as given by the following equations, where Q₁ represents the demand for Firm 1 and Q₂ represents the demand for Firm 2:
\[ Q_1 = a - P_1 + bP_2 \]
\[ Q_2 = a - P_2 + bP_1 \]

Using these equations it can be seen that if Firm 1 increases its price it will have a negative impact on its own demand, while having a positive impact on Firm 2’s demand (through the substitution effect). In this model the parameter \( a \) represents a ceiling for each firm’s demand and the parameter \( b \) controls for the magnitude of the substitution effect. Furthermore, the parameter \( b \) is restricted to values between 0 and 1 (inclusive). Finally, the parameters \( a \) and \( b \) need not be symmetric for both firms, although they will be treated as such for the purposes of the following analyses.

The profit for each firm is calculated as the product of the net revenue per unit (price minus cost) and the number of units sold (demand), or:

Profit for Firm 1, \[ \pi_1 = (P_1 - C_1)(a - P_1 + bP_2) \]
Profit for Firm 2, \[ \pi_2 = (P_2 - C_2)(a - P_2 + bP_1) \]

Where \( C_1 \) and \( C_2 \) represent the marginal cost of production for Firm 1 and Firm 2 respectively. The game is solved by establishing each firm’s best-response curve, which is then used to determine equilibrium prices. These equilibrium prices are then used to calculate the resulting profit for each firm. Firm 1’s best response (BR\(_1\)), when faced with any \( P_2 \), is to choose a \( P_1 \) that maximizes its profit. Therefore,

\[
\text{BR}_1: \frac{d\pi_1}{dP_1} = 0
\]
\[ \pi_1 = (P_1 - C_1)(a - P_1 + bP_2) \]
\[ \pi_1 = -X_1(a + bP_2) + (a + bP_2 + C_1)P_1 - P_1^2 \]
\[ \frac{d\pi_1}{dP_1} = a + bP_2 + C_1 - 2P_1 \]
\[ 0 = a + bP_2 + C_1 - 2P_1 \]
\[ 2P_1 = a + bP_2 + C_1 \]

Because the profit curves of the two firms are symmetric in respect to the parameters \( a \) and \( b \), Firm 2’s best response can be solved similarly, resulting in the following equations:

\[
\text{BR}_1: P_1 = (a + C_1)/2 + (b/2)P_2 \\
\text{BR}_2: P_2 = (a + C_2)/2 + (b/2)P_1
\]

This system of equations can be solved using substitution in order to find the Nash Equilibrium prices \( P_1^* \) & \( P_2^* \), in general terms, which will result from this price competition. Such calculations for \( P_2^* \) are provided below, while \( P_1^* \) can be derived from symmetry.

\[ P_1 = (a + C_1)/2 + (b/2)P_2 \]
\[ P_2 = (a + C_2)/2 + (b/2)P_1 \]
\[
P_2 = \frac{(a + C_2)/2 + (b/2) [(a + C_1)/2 + (b/2)P_2]}{2} + \frac{b}{2}P_2
\]

\[
P_2 = \frac{(a + C_2)/2 + (ab + bC_1)/4 + (b^2/4)P_2}{2} 
\]

\[
P_2 = (2a + 2C_2 + ab + bC_1) / (4 - b^2)
\]

\[
P_2^* = \frac{[2(a + C_2) + b(a + C_1)]/[(4 - b^2)]}{2} \quad \text{(Eq. 1)}
\]

\[
P_1^* = \frac{[2(a + C_1) + b(a + C_2)]/[(4 - b^2)]}{2} \quad \text{(Eq. 2)}
\]

Although we have now solved for (in general terms) the equilibrium prices that result from this type of price competition, the Dixit and Skeath (2004) model must be augmented in order to consider the effects of environmental regulation and the resulting innovation decisions. For the purposes of this analysis we will assume that a firm’s decision to innovate will lead to a reduction in that firm’s marginal cost, as supported by the case studies presented in Section 4. Therefore, Firm 1 and Firm 2 will be playing a simultaneous move game that now effectively has two stages: (1) The firms must decide whether or not to invest in an R&D project that will serve to lower marginal cost, and (2) the firms must then choose a price for their products given the new cost structure that the firms will face. In order to solve this game, each firm must now consider the profit it will achieve given the different combinations of investment decision outcomes and price structure possible (see Figure 1).

**Investment Decisions**

<table>
<thead>
<tr>
<th>Firm 1</th>
<th>Invest</th>
<th>Not Invest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Invest</td>
<td>(\xi)</td>
<td>(\xi)</td>
</tr>
<tr>
<td>Not Invest</td>
<td>(C)</td>
<td>(\xi)</td>
</tr>
</tbody>
</table>

**Figure 1.** Cost structures for various investment decision combinations, where \(C > \xi > 0\) and \(\xi\) represents a decrease in the marginal cost of production for firms that choose to invest in new technology.

*Note: This does not represent a payoff matrix for the firms relative to investment decisions.*

Although this game is described as having two stages, for all intents and purposes the firms face only one simultaneous decision. That is to say, in order to solve this game each firm will first analyze the resulting profit at each cost structure by determining the equilibrium prices in each scenario; then, by comparing the resulting profits the firms will make their investment decisions and reach an overall equilibrium. In order to solve for equilibrium prices, and thus inform investment decisions, the firms must consider two scenarios: (1) When costs are symmetric, as in the case of the strategies \((\text{Invest, Invest})\) or \((\text{Not Invest, Not Invest})\), and (2) when costs are asymmetric, as in the case of \((\text{Invest, Not Invest})\) or \((\text{Not Invest, Invest})\).

In the case of symmetric costs, the substitution \(C_1 = C_2 = C\) can be made Equation 1, which now becomes:

\[
P_2^* = \frac{[2(a + C) + b(a + C)]/[(4 - b^2)]}{2}
\]
Furthermore, because both firms are symmetric about the parameters $a$ and $b$ as well, the above equation can be generalized for either Firm 1 or Firm 2. Finally, this equation can then be simplified to determine the equilibrium price, $P^*$, for both firms under symmetric cost conditions as follows:

$$P^* = \frac{[2(a + C) + b(a + C)]}{[(4 - b^2)]}$$

$$P^* = \frac{[2(a + C) + b(a + C)]}{[(2 + b)(2 - b)]}$$

$$P^* = \frac{[(2 + b)(a + C)]}{[(2 + b)(2 - b)]}$$

$$P^* = \frac{(a + C)}{2 - b}$$  \hspace{1cm} (Eq. 3)

Thus, under symmetric cost conditions the profit for each firm, $\pi$:

$$\pi = (P^* - C)(a - P^* + bP^*)$$

$$\pi = -aC + (a + C - bC)P^* + (b - 1)(P^*)^2$$

$$\pi = -aC + (a + C - bC)[(a + C)/(2 - b)] + (b - 1)[(a + C)/(2 - b)]^2$$

$$\pi = [(a - C)^2 + bC(bC + 2a - 2C)]/(2 - b)^2$$

In order to differentiate between the different levels of profit achieved in the two different instances of symmetric cost, an upper case pi, $\Pi$, will denote the profit that is achieved by investing in technology in order to reduce marginal cost. Therefore, the profit equations for symmetric cost are more accurately represented as:

$$\pi = [(a - C)^2 + bC^2(2a - 2C)]/(2 - b)^2$$  \hspace{1cm} (Eq. 4)

$$\Pi = [(a - \phi)^2 + b\phi^2(2a - 2\phi)]/(2 - b)^2$$  \hspace{1cm} (Eq. 5)

In considering the case of asymmetric costs, the substitution $C_1 = C_2 = C$ can no longer be made into Equations 1 & 2. Therefore the equilibrium prices $P_1^*$ and $P_2^*$ must remain unique, and under these conditions the profit for Firm 1, $\pi_1$ can be calculated as follows:

$$\pi_1 = (P_1^* - C_1)(a - P_1^* + bP_1^*)$$

$$\pi_1 = -aC_1 + (a + C_1)P_1^* - bC_1P_2 + bP_1^*P_2^* - (P_1^*)^2$$

* substitute $P_1^* & P_2^*$ from Eqs. 1 & 2, then simplify...

$$\pi_1 = \frac{[4a^2 + 4a^2b + 4abC_2 + 4C_2^2 - 4abC_1 - 4bC_1C_2 - 4b^2C_1^2 + 2ab^3C_1 + 2b^3C_1C_2 + b^4C_2^2 + 4ab^2C_1 + 2ab^2C_2 + b^2C_2^2 - 8aC_1 + a^2b^2]}{(4 - b^2)^2}$$  \hspace{1cm} (Eq. 6)

It follows then from symmetry that the profit for Firm 2, $\pi_2$:

$$\pi_2 = \frac{[4a^2 + 4a^2b + 4abC_1 + 4C_2^2 - 4abC_2 - 4bC_1C_2 - 4b^2C_2^2 + 2ab^3C_2 + 2b^3C_1C_2 + b^4C_2^2 + 4ab^2C_1 + 2ab^2C_2 + b^2C_2^2 - 8aC_2 + a^2b^2]}{(4 - b^2)^2}$$  \hspace{1cm} (Eq. 7)
Note: It would be more accurate to represent the different costs to the firms as \( C_1 \) and \( C_2 \) in the case when Firm 2 chooses to invest while Firm 1 does not and vice versa, but for simplicity the above equations can be used to represent profit in either case.

Furthermore, just as in the case of symmetric costs, the symbols \( \Pi_1 \) and \( \Pi_2 \) will be used to denote the profit achieved by firms that choose to invest in technology that will reduce marginal cost, while \( \pi_1 \) and \( \pi_2 \) will be used to represent the profit of a firm that chooses not to invest. Finally, in order to generate a payoff matrix that encompasses the total cost to each firm of choosing whether to invest in new technology there must be some fixed cost, \( F \), associated with the decision to invest in new technology. Therefore, the final payout matrix for this price-competition game is given in Figure 2.

**Price Competition Payoff Matrix**

<table>
<thead>
<tr>
<th>Firm 1</th>
<th>Firm 2</th>
<th>Invest</th>
<th>Not Invest</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Invest</td>
<td>( \Pi - F )</td>
<td>( \Pi_1 - F )</td>
</tr>
<tr>
<td>Invest</td>
<td>( \Pi - F )</td>
<td>( \Pi_1 - F )</td>
<td>( \pi_2 )</td>
</tr>
<tr>
<td>Not Invest</td>
<td>( \pi_1 )</td>
<td>( \Pi_2 - F )</td>
<td>( \pi )</td>
</tr>
</tbody>
</table>

**Figure 2.** Total profit to be achieved by each firm in each of the cost structures outlined in Figure 1. \( \pi \) represents the profit achieved by choosing not to invest while \( \Pi \) represents the profit achieved by choosing to invest, with \( F \) representing the fixed cost associated with R&D expenditures. Note: The subscripts serve to distinguish the different levels of profit achieved when firms face asymmetric costs, while no subscripts are needed to distinguish the profit achieved by firms facing symmetric costs.

Using the above framework, two cases will now be considered which shed light on how environmental regulation can foster innovation in firms that would choose not to innovate otherwise. First, this analysis will consider why some firms will choose not to undertake R&D projects that provide a net economic benefit to the firm because of risk aversion, and then show how environmental regulation can shift the game’s equilibrium to encourage investment. Second, this analysis will consider how environmental regulation can be used to induce an R&D race that will lead to a net economic benefit to the winning firm through license fee revenues, even when such a project would not be financially attractive before regulation.

In the following exercises payoff matrices will be presented in the same format as given in Figure 2, with profits calculated using Equations 4, 5, 6, and 7 and net profits calculated considering any fixed cost, \( F \), or license fee, \( L \). The strategies of each firm, either Invest or Not Invest, will be indicated by underlining the corresponding payoff, and thus a Nash Equilibrium solution to each game will be any square which has both payoffs underlined.

5.4 Exercise 1: Risk Aversion

This exercise supports the argument that innovation resulting from environmental regulation serves to benefit firms economically by reducing their costs. It further explains why firms would require environmental regulation in order to take advantage of
these investment opportunities, even though such projects would have provided net benefit to the firm anyway. To begin this exercise, we must first construct a payoff matrix which has a Nash Equilibrium of \((\text{Invest, Invest})\), or in other words features parameters which make investing in R&D projects to develop new cost-saving technology financially attractive to firms. The following parameters and resulting payoff matrix achieve this goal:

\[
\begin{array}{c|cc}
\text{Firm 1} & \text{Invest} & \text{Not Invest} \\
\hline
\text{Invest} & 2506 & 2506 \\
\text{Not Invest} & 2401 & 2612 \\
\end{array}
\]

\[
\begin{array}{c|cc}
\text{Firm 2} & \text{Invest} & \text{Not Invest} \\
\hline
\text{Invest} & 2612 & 2401 \\
\text{Not Invest} & 2500 & 2500 \\
\end{array}
\]

\[a = 100\]
\[b = .5\]
\[C = 50\]
\[\epsilon = 42.5\]
\[F = 250\]

**Figure 3.** Payoff matrix using parameters that result in a Nash Equilibrium of \((\text{Invest, Invest})\), meaning that under the cost structure defined by the given parameters the ensuing price competition would make investing in cost-saving technology economically beneficial to firms.

Here, the parameters are chosen in order to reasonably represent real-world market conditions (i.e. fixed cost should be high relative to savings from marginal cost reductions and marginal cost reductions should be small relative to marginal cost). However, in order to suit our purposes of illustrating a financial advantage to investing in cost-saving technology, the marginal cost savings of the technology is chosen to be 15% and the fixed cost of the project is relatively low (investing $250 saves $7.25 in cost per unit). Nevertheless, these parameters accurately reflect the type of financially attractive investments that the firms described in Section 4 likely faced.

Given these attractive payoffs, a simple explanation for why firms will avoid investments in R&D to create new cost-saving technologies arises from the concept of risk aversion. Because there is inherent uncertainty in whether a firm’s R&D project will succeed in developing technology that will indeed benefit the firm, a firm may choose to avoid undertaking risky R&D projects even when such investments have projected net benefits. Thus, firms will discount the expected profits of uncertain projects according to their level of risk aversion, and more favorably value profits that can be achieved with certainty.

For example, suppose that in undertaking an R&D project a firm has a fifty-percent chance of the project succeeding, in which case it earns $100 in extra profit, and a fifty-percent chance of the project failing and earning $0 extra. Next, suppose a firm scales the payoff (or utility) of its investments by square rooting the expected profit. Under these conditions, the prospect of earning $100 is equal to a payoff of 5 to the firm \(( .5 \times \sqrt{100} + .5 \times 0 )\), which is exactly the same as the firm receiving $25 for certain \((\sqrt{25} = 5)\).

Here the firm is characterized as risk averse, because it is willing to sacrifice the difference between the expected value of the investment, $50 (or \(.5 \times 100 + .5 \times 0\)), in order to receive $25 for certain. Figure 4 provides a graph of this analysis of risk
aversion, showing the square root scaling of profits, the expected value of the investment, and the firm’s indifference between the certain profit and the investment prospect.

![Risk Aversion Graph]

Figure 4. Graph displaying a firm’s risk aversion, with the square-root scale shown in red, the expected value of the investment shown in black, and the indifference of the firm between the certain profit of $25 and the fifty-fifty chance of $100 shown by the dashed line.

This type of risk aversion to uncertain R&D project can be incorporated into the payoff matrix shown above, and can be used to explain how environmental regulation can foster innovation. Suppose that the firms are facing the same parameters and payoff matrix as proposed in Figure 3, but also scale their payoffs by square rooting expected profits and additionally believe that the R&D project only has a fifty-percent chance of reducing their marginal cost. A conceptual payoff matrix showing how the scaled payoffs are now calculated is shown below in Figure 5.

Matrix Showing Calculations for Scaled Payoffs

<table>
<thead>
<tr>
<th>Firm 1</th>
<th>Invest (I)</th>
<th>Not Invest (NI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>p*√(Π₁) + p*(1-p)<em>√(Π₁-F) + p</em>(1-p)*√(Π₁-F)</td>
<td>p*√(Π₁) + p*(1-p)*√(Π₁-F)</td>
</tr>
<tr>
<td></td>
<td>p*√(Π₂) + p*(1-p)<em>√(Π₂-F) + p</em>(1-p)*√(Π₂-F)</td>
<td>p*√(Π₂) + p*(1-p)*√(Π₂-F)</td>
</tr>
<tr>
<td>Firm 2</td>
<td>p*√(Π₁) + p*(1-p)*√(Π₁-F)</td>
<td>p*√(Π₂) + p*(1-p)*√(Π₂-F)</td>
</tr>
<tr>
<td></td>
<td>p*√(Π₁ - F) + (1-p)*√(π - F)</td>
<td>p*√(Π₂ - F) + (1-p)*√(π - F)</td>
</tr>
<tr>
<td></td>
<td>p*√(π₁) + (1-p)*√(λ)</td>
<td>p*√(π₂) + (1-p)*√(λ)</td>
</tr>
</tbody>
</table>

Figure 5. Payoff matrix demonstrating how to calculate the scaled payoffs for risk averse firms. The parameter p represents the probability of an R&D project succeeding, while (1-p) represents the probability that it will fail. As in Figure 2, Π is used to denote higher profit that is achieved through marginal cost reductions, while π represents the lower level of profit that is achieved at the original level of marginal cost. The subscripts serve to denote the profits achieved under asymmetric cost structures, while profit symbols without subscripts represent those achieved under symmetric cost structures (see Section 5.3).

Using the calculations shown in Figure 5, the scaled payoffs that each firm will receive can now be analyzed to show how uncertainty in R&D projects can lead to a shift in the
equilibrium solution of the game presented in Figure 3 away from (Not Invest, Not Invest). The scaled payoff matrix reflecting these conditions is shown in Figure 6.

**Scaled Payoff Matrix for Risk Averse Firms**

<table>
<thead>
<tr>
<th></th>
<th>Firm 2</th>
<th>Probability of success = .5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Invest</td>
<td>Not Invest</td>
</tr>
<tr>
<td>Firm 1</td>
<td>48.75</td>
<td>48.75</td>
</tr>
<tr>
<td></td>
<td>49.27</td>
<td>49.5</td>
</tr>
<tr>
<td>Not Invest</td>
<td>49.5</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>49.27</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>50</td>
</tr>
</tbody>
</table>

Figure 6. Payoff matrix using the same parameters as in Figure 3 but scaled to show a risk aversion. Here the firms’ payoffs are calculated by square rooting the expected profits to be received if each firm has fifty-percent chance of its R&D project reducing its costs. Under these conditions the Nash Equilibrium shifts to (Not Invest, Not Invest).

Each firm’s risk aversion has shifted the Nash Equilibrium of this scaled payoff matrix to (Not Invest, Not Invest), which is preventing them from receiving the net benefit provided by investing in R&D, as shown in Figure 3. It is important to realize that the numbers in the scaled payoff matrix in Figure 5 do not represent the actual expected profit that each firm will realize, but rather is a representation of the payoff or utility that the firms will receive from making decisions about uncertain investments in new R&D projects. For this reason, the firms will choose their strategies of Not Invest based on this scaled payoff matrix, even though they understand that investing could potentially provide them with a net increase in profits.

This outcome can be changed however by the influence of environmental regulation. As Porter and van der Linde point out, regulation can serve to, “signal companies about resource inefficiencies & potential technological improvements,” as well as, “reduce uncertainty that investments to address the environment will be valuable” (Porter and van der Linde 1995, pp. 99-100). More specifically, by attaching a new cost to certain resources, properly crafted environmental regulation can send signals to companies that investing in R&D projects focused on creating new technologies that will reduce inputs of these costly resources will have a higher probability of saving the company money. Therefore, environmental regulation can effectively cause companies to assign higher probabilities of success to R&D projects.

As seen in Figure 7, an increase in the probability of success to seventy percent results in a shift in the Nash Equilibrium of this game to induce firms to begin investing in R&D. At this level, the equilibria become (Invest, Not Invest) and (Not Invest, Invest), which although they affect the firms’ payoffs unequally still result in higher combined profit for the two firms (see Figure 3). Furthermore, Figure 6 also shows that another increase in the probability of success to just seventy-one percent results in the more favorable equilibrium (Invest, Invest).
Scaled Payoff Matrices for Risk Averse Firms with Environmental Regulation

<table>
<thead>
<tr>
<th>Firm 1</th>
<th>Invest</th>
<th>Not Invest</th>
<th>Probability of success = .7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Invest</td>
<td>49.30</td>
<td>50.01</td>
<td></td>
</tr>
<tr>
<td>Not Invest</td>
<td>49.27</td>
<td>49.30</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Firm 1</th>
<th>Invest</th>
<th>Not Invest</th>
<th>Probability of success = .71</th>
</tr>
</thead>
<tbody>
<tr>
<td>Invest</td>
<td>49.30</td>
<td>50.04</td>
<td></td>
</tr>
<tr>
<td>Not Invest</td>
<td>49.29</td>
<td>49.29</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 7.** Payoff matrix reflecting the increased probability of success afforded by environmental regulation. In both cases, the Nash Equilibria have shifted to away from *(Not Invest, Not Invest)* demonstrating how environmental regulation can be effective in inducing innovation.

5.5 Exercise 2: Licensing Fees

This exercise supports the argument that innovation resulting from environmental regulation serves to benefit firms economically by providing additional revenues from license fees. It further explains why firms would require environmental regulation in order to take advantage of licensing fees, because the regulation creates a market for new products that satisfy the need of all firms within an industry to meet more stringent levels of compliance.

For this exercise we must first construct a matrix which results in the Nash Equilibrium strategies *(Not Invest, Not Invest)*, indicating that investing in a certain type of R&D project to reduce cost is not initially financially attractive to either firm. Furthermore, the parameters chosen should again reasonably represent real-world conditions (i.e. fixed cost should be high relative to savings from marginal cost reductions, marginal cost reductions should be small relative to marginal cost, and the substitution effect should not be one to one). Figure 8 provides a set of parameters and the resulting payoff matrix that would discourage firms from investing in new technology.

**License Fee Payoff Matrix – Before Environmental Regulation**

<table>
<thead>
<tr>
<th>Firm 1</th>
<th>Invest</th>
<th>Not Invest</th>
<th>a = 100</th>
<th>b = .5</th>
<th>C = 50</th>
<th>c = 45</th>
<th>F = 300</th>
<th>L = 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Invest</td>
<td>2369</td>
<td>2439</td>
<td>2439</td>
<td>2434</td>
<td>2500</td>
<td>2500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not Invest</td>
<td>2434</td>
<td>2439</td>
<td>2500</td>
<td>2500</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 8.** Payoff matrix constructed to demonstrate conditions in which it would not be financially beneficial for a firm to invest in cost-saving technology before the introduction of license fees.

As shown above, under these conditions the dominant strategy for both firms is to choose *Not Invest*. Although the investment in R&D to develop new technology reduces a firm’s cost by 10%, the high fixed cost of the investment makes the decision economically...
unattractive. Furthermore, because the firm that chooses not to invest in R&D does not have access to the newly developed technology it cannot benefit from reducing its marginal cost either. Under these conditions innovation diminishes the overall profit of the market, and the firms perform best when they choose not to invest in new, cost-saving technology.

However, using the same parameters as above it can be shown that environmental regulation has the ability to shift the Nash Equilibrium in this game and improve overall profits by introducing revenues from a license fee. Because environmental regulation would mandate compliance, a firm that chooses not to innovate would have to pay a fee in order to license the new technology from the other firm that has developed technology to meet the new standards. Here, the license fee would not only be a reward for the firm that chooses to invest in R&D in order to develop new technology, but would also be a punishment for the firm that chooses not to invest.

For the purposes of this analysis, the license fee, $L$, will be considered as a lump sum payment that one firm must pay to the other in order to have access to the newly developed technology. Because the firm is paying the license fee in order to obtain access to the new, cost-saving technology it will benefit from reducing its marginal cost. Finally, if both firms choose to invest neither will benefit from receiving a license fee because each already has access to the required technology. As such, the payoff matrix will take on the new characteristics shown below in Figure 9.

\[
\begin{array}{c|cc|cc}
\text{Firm 1} & \text{Invest} & \text{Not Invest} \\
\hline
\text{Invest} & \Pi - F & \Pi - F & \Pi - F + L & \Pi - L \\
\text{Not Invest} & \Pi - L & \Pi - F + L & \pi & \pi \\
\end{array}
\]

**Figure 9.** Total profit to be achieved by each firm with the advent of license fees. Because licensing allows for the transfer of technology between firms, firms will face symmetric cost structures when at least one firm invests in R&D, and will also achieve higher profits, $\Pi$, due to marginal-cost savings.

Figure 10 provides three payoff matrices, using the same parameters as in Figure 7 and a range of license fee values, which show critical values of $L$ (such that $0 < L < F$) that shift the Nash Equilibrium away from (Not Invest, Not Invest). From these payoff matrices it can be seen for that any $L$ such that $0 < L < 130.555\ldots$ the Nash Equilibrium of the game remains (Not Invest, Not Invest). However, for values of $L$ such that $130.555\ldots < L < 300$ the Nash Equilibrium of the game is either (Invest, Not Invest) or vice versa. Finally, as the value of the license fee increases above 300, or the value of $F$, the Nash Equilibrium will shift to (Invest, Invest). Therefore, all values of $L$ greater than or equal to $130.555\ldots$ represent the success of environmental regulation in encouraging innovation in firms which previously had no incentive to pursue such projects.
License Fee Payoff Matrices – Critical Values of L

### L = 130.555...

<table>
<thead>
<tr>
<th>Firm 1</th>
<th>Firm 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Invest</td>
<td>Not Invest</td>
</tr>
<tr>
<td>Invest</td>
<td>2369 2369 2500 2539</td>
</tr>
<tr>
<td>Not Invest</td>
<td>2539 2500 2500 2500</td>
</tr>
</tbody>
</table>

### L = 150

<table>
<thead>
<tr>
<th>Firm 1</th>
<th>Firm 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Invest</td>
<td>Not Invest</td>
</tr>
<tr>
<td>Invest</td>
<td>2369 2369 2519 2519</td>
</tr>
<tr>
<td>Not Invest</td>
<td>2519 2519 2500 2500</td>
</tr>
</tbody>
</table>

### L = 300

<table>
<thead>
<tr>
<th>Firm 1</th>
<th>Firm 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Invest</td>
<td>Not Invest</td>
</tr>
<tr>
<td>Invest</td>
<td>2369 2369 2669 2369</td>
</tr>
<tr>
<td>Not Invest</td>
<td>2369 2669 2500 2500</td>
</tr>
</tbody>
</table>

**Figure 10.** Payoff matrices demonstrating the effect of license fee payments on equilibrium strategies. As the value of the license fee increases from zero firms are incentivized to undertake investments in new, cost-saving technology.

Because regulation is not necessarily a prerequisite for firms to share technology among competitors, there is some question as to why regulation would be necessary in order to induce licensing when there are clear benefits even at low levels of license fees. However, when $130.555... < L < 150$, although the firms have equilibrium strategies of $(Invest, Not Invest)$ and vice versa, the firm that employs the strategy $Not Invest$ actually realizes a higher profit. That is, although the revenue from the license fee is high enough to encourage innovation it is not sufficiently high enough to reward the firm that chooses to invest in R&D more than the other firm who simply licenses the cost-saving technology. Under these conditions, it is unrealistic that any firm would move away from the equilibrium of $(Not Invest, Not Invest)$.

Therefore, environmental regulation becomes an important incentive in allowing firms to shift away from this equilibrium. Because the government is mandating compliance, at least one firm must invest in order to develop new technology. As such, this requirement induces an R&D race in which one firm will choose to invest in the new technology and thus shift the equilibrium away from $(Not Invest, Not Invest)$. Furthermore, in order to properly incentivize R&D investments, environmental regulation is required in order to guarantee sufficiently high values of L that will provide a greater benefit to firms that choose to invest. Once license fees become valued higher than 150, or half the cost of F, then the firm that chooses the strategy to invest enjoys a greater benefit than the firm that must license the technology, a condition that more accurately reflects the benefits of licensing as described in Section 4.
Environmental regulation can guarantee higher valuation of licenses for the sharing of technology across an industry in much the same way that it reduces uncertainty in R&D investments in new, cost-saving technology. By signaling to companies that certain inputs will become more expensive the regulation will create a higher demand for new technologies that will reduce the need for these inputs and thus save companies money. This increased demand will result in a firm’s willingness to pay a higher price in order to access new technologies.

Finally, it is important to note that for values of $L$ above $130.555\ldots$ (or roughly 43.5% of the fixed cost of investing) when one firm is incentivized to spend on R&D, the joint profit earned by the firms after innovation will be higher than the total profit realized before environmental regulation fostered this shift in the equilibrium. This is due to the fact that ability to transfer technology between firms as a result of licensing allows for both firms to benefit from cost-saving technologies without both firms having to invest the full fixed cost of the technology, $F$. The licensing fee effectively distributes the fixed cost of R&D among more than one firm, allowing the investment to become profitable and allowing all firms within a given market to reduce their marginal cost.

At first the high values of $L$ needed to make environmental regulation beneficial may seem like an unrealistic amount for one firm to charge another in order to license a newly developed technology. However, as the number of firms in the market increases this total revenue from license fees can be divided among several competitors. Thus the individual penalty becomes more reasonable, while the aggregate revenue is more likely to exceed this critical value. Therefore, a greater number of firms competing in a given market would increase the likelihood of success of environmental regulation, as the revenue of license fees increases for the firm that wins the R&D race while the cost to other firms decreases.

5.6 Summary

Although the exercises here have successfully demonstrated two ways in which environmental regulation can have a beneficial impact on innovation decisions, these mechanisms are by no means the only ones that can be explored using this price competition model. For example, in the case of GE Transportation much of the success that resulted from developing a new, more efficient diesel locomotive came in the form of increased demand for a “green” product. Using this same model of price competition between two firms, one could easily explore this mechanism through the manipulation of the parameters $a$ and $b$, which respectively represent demand and the substitution effect, in order to demonstrate how an increase in demand as a result of environmental regulation can provide enough incentive to undertake R&D spending to develop more efficient technologies.
6 Conclusion

Using a simple model of price competition between two firms it has been shown that environmental regulation can effectively induce innovation through spending on R&D projects to develop more efficient technology. This technology lowers the firm’s costs by reducing the consumption of resources used as inputs. The innovation described here provides firms with a net benefit by sufficiently increasing profits to overcome the cost of investing, while simultaneously benefiting the consumer through reduction of the negative externalities associated with the production of goods. However, these benefits are only realized with the introduction of environmental regulation, because regulation is necessary in order to reduce uncertainty in R&D investments or to provide additional revenue in the form of licensing fees paid out to share technologies across an industry. Therefore, as a result of environmental regulation firms are incentivized to participate in investment decisions that they would not have otherwise, and as a result the firm, the industry, and the consumer benefit.

Although the exercises presented here are obviously constructed to suit the purpose of supporting the Porter Hypothesis they are nevertheless worthwhile in modeling firm behavior that is representative of real-world conditions. This analysis highlights risk aversion as a major shortcoming in firm behavior that prevents them from effectively identifying profitable investment opportunities. Due to this limitation, there are likely a significant number of investment opportunities available to companies right now that are not being taken advantage of. Despite this fact, we see a small number of firms, as demonstrated by the case of HP, that are willing to explore these opportunities. HP has provided clear evidence to show that these investments have simultaneously benefited the firm through cost-saving measures and reduced the environmental impact of their business. That a company like HP pursues these opportunities without being forced by the hand of regulation stems from a unique management strategy and company culture. Therefore, regulation is necessary in order to spread this strategy to a greater number of firms and a greater number of industries.

Furthermore, this analysis also indicates that there are likely an equal number of investment opportunities being consider by companies now that simply do not provide the financial incentives necessary to spend money in order to create more efficient technologies. In the case of GE Transportation and the Honda Civic, expensive projects to redesign engines would likely not have been pursued without the presence of more stringent regulation. However, this analysis has demonstrated that if environmental regulation can begin to effectively guarantee a sufficiently high value for new technologies then firms can more consistently realize net benefits through technology sharing and licensing revenues just as GE and Honda have done. Therefore, by better understanding how environmental regulation will impact market dynamics, especially through the advent of licensing fees, environmental regulation can be used to make these once unprofitable investments more financially attractive, benefiting the firm, the industry, and the consumer.
7 References


