

**THE IMPACT OF ENVIRONMENTAL REGULATION ON  
TECHNOLOGICAL INNOVATION**

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Major Paper submitted to the  
Department of Economics of the University of Ottawa

In partial fulfillment of the requirements of the

M.A. degree in Economics

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Ottawa, Ontario

August 2013

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## **Abstract**

This paper reviews the existing theoretical and empirical literature on the relationship between environmental regulation and technological innovation. The paper begins with a review of the most commonly used environmental policies, and then specifies the motivation of technological innovation led by environmental regulations by reviewing several key theoretical and empirical studies. Following this discussion, the paper explains how conventional and evolutionary regulation instruments affect technological innovation in different industrial sectors. In this section, a significant trend, which reveals how the central role of governmental regulation in motivating environmental innovation has begun to weaken in recent years due to the emergence of new motivations from inside and outside the industry, is explored. The next section examines two industrial sectors in terms of the current regulatory policies and regulatory trends. In the last section of the paper, I review several recent studies, which analyze the new role environmental regulation plays in innovation. The aim of this section is to explain why some firms are willing to engage in costly R&D investment to exceed environmental regulations. To conclude, this paper will provide the reader with a clear understanding of the relationship between environmental regulation and innovation.

## **Acknowledgement**

First of all, I would like to thank Professor Gamal Atallah for his generous support and insightful comments throughout the process of writing this paper, his great patience and encouragement was a huge impetus for me to work hard. I am also grateful to Professor Jean-Thomas Bernard for his extremely valuable feedback. I would also like to thank the most wonderful Avery Steinberg for her talented critique and comments on my writing.

## 1. Introduction

In the last few decades, environmental regulations have been integrated into many industrial sectors including but not limited to manufacturing, clean energy, and natural resources. More and more countries are taking action to protect the environment by implementing regulations in order to limit the negative externalities caused by environmental destruction. Firms take into account environmental factors in almost every vital decision they make, not only to react to stringent environmental regulations, but also to establish an image of environmental friendliness to satisfy customers who are increasingly concerned about the environment. At the same time, the issue stirs up a large debate among economists over whether environmental regulation is an opportunity to attain more benefits through investing in innovation or whether it is an additional cost burden that will hurt economic growth.

To better understand this issue, this paper discusses some commonly used environmental regulatory instruments, including command and control and incentive-based instruments. Both approaches have been well researched and compared regarding their economic and environmental performance. Kemp and Pontoglio (2011) specify three criteria for measuring the performance of environmental policy instruments: the expected environmental benefits, the costs of the policy instruments, and the effect on innovation.

Many environmental movement supporters and regulators who are “eager to avoid being seen as imposing unwanted costs on business or lower levels of government” (Palmer et al., 1995, p.120) tend to accept that businesses should take into account not only the pressure for environmental protection, but also that this approach may generate more profit and allow business to become increasingly competitive through innovation, namely a “win-win” situation which is known as a strong version of the Porter Hypothesis (Ambec et al., 2013). Many researchers have looked into this argument in the past 20 years (Greaker, 2003; Kennedy, 1994; Mohr, 2002). Results from these studies examine many subjects such as the increasing competitiveness generated by regulation, the costs saved by innovation, and how innovation is affected by environmental regulation.

Strict environmental regulations often motivate firms to discover new eco-friendly technologies (Palmer et al., 1995). The incentives for a firm to invest in pollution-control and implement costly new technologies discovered by itself or others, are determined by analyzing the relationship between environmental regulation and innovation. It is reasonable to believe that the stringency of regulatory instruments may have substantial effects on the level of innovation in terms of R&D investment and vice versa. For example, the impact of environmental regulations is taking place throughout developed and developing countries, where firms are increasingly investing in R&D and lobbying efforts in an attempt to mitigate or change the level of environmental standards based on their newly invented technology in order to achieve a competitive advantage.

Technological innovation, being an outcome of these environmental regulations, can affect the structure of industrial sectors. For example, a firm investing in R&D or utilizing some type of new technology has a higher chance of increasing its profit and market share. Jaffe and Palmer (1997) confirm this causal relationship by indicating that intensive environmental regulations are considered as an incentive for polluters to apply or create new and less expensive methods of reducing pollution or potentially entirely new, cheaper methods of production that eliminate particular types of emissions. Jaffe and Palmer (1997) also quote Michael Porter's view, indicating that: "If one country adopts stricter environmental regulations than its competitors, the resulting increase in innovation will enable that country to become a net exporter of the newly developed environmental technologies" (1997, p. 610).

Porter's view of environmental regulation achieved vast success and a large amount of literature, both theoretical and empirical, has been dedicated towards verifying the validity of his claims. Consequently, the topic of how environmental regulations affect innovation is becoming an increasingly important topic for regulators.

On the other hand, many regulation standards are formulated based on forward thinking, which allows regulators to impose a standard no existing technology may meet. As a result, regulators may not settle on one particular standard if no firm is capable of achieving it. In other

words, firms may strategically choose to innovate, which furthermore may cause backlash from firms incapable of meeting the regulatory standard (Puller, 2006). For example, firms with large pollution discharge are more willing to innovate themselves to receive the benefit from government subsidies and gain more market share in an imperfect market.

This paper reviews the existing theoretical and empirical literature on the relationship between environmental regulation and technological innovation. The paper begins with a review of the most commonly used environmental policies, and then specifies the motivation of technological innovation led by environmental regulations by reviewing several key theoretical and empirical studies. Following this discussion, the paper explains how conventional and evolutionary regulation instruments affect technological innovation in different industrial sectors. In this section, a significant trend, which reveals how the central role of governmental regulation in motivating environmental innovation has begun to weaken in recent years due to the emergence of new motivations from inside and outside the industry, is explored. The next section examines two industrial sectors in terms of the current regulatory policies and regulatory trends. In the last section of the paper, I review several recent studies, which analyze the new role environmental regulation plays in innovation. The aim of this section is to explain why some firms are willing to engage in costly R&D investment to exceed environmental regulations. To conclude, this paper will provide the reader with a clear understanding of the relationship between environmental regulation and innovation.

## **2. Instruments of environmental regulation**

Economists traditionally treated environmental deterioration as a microeconomic issue, focusing on the impact of pollution on scarce natural resources such as water and air, before official environmental regulations existed. Pollution was not accurately measured in terms of the economic cost on many aspects of society, which led economists to consider implementing a cost tied to causing environmental deterioration such as an effluent fee. However, these suggestions

failed to make a legislative impact on environmental regulations.

Nonetheless, pollution activities continued to draw enormous public attention and concerns over the potentially large cost of healthcare expenditure and social welfare loss, which eventually led to a surge of U.S. federal legislature during the 1970s. Two examples are the Clean Air Act of 1970 and the Water Pollution Control Act Amendments of 1972, which provided a new perspective of setting environmental regulatory standards by placing more emphasis on social welfare benefits than economic benefits (Cropper and Oates, 1992). Social welfare, for example, is related to how regulations help maintain public health in fighting environmental deterioration. As a result of these Acts, a large amount of economic resources are utilized for the abatement of environmental damage. Environmental regulation eventually pushed economic concerns into the spotlight given the concerns of cost, which places a large burden on production and generating profit (Jorgenson and Wilcoxon, 1990). In response to this heightened economic concern, US President Ronald Reagan's Executive Order 12291, formalized in 1981, advocated for a large number of environmental standards based on cost-benefit analysis.

Many economic incentives (also known as market-based instruments) to control waste continue to gain popularity in the list of regulatory instruments. In the United States, for example, the 1977 Amendments to the Clean Air Act introduced a provision for “emission offsets” that has evolved into the Emissions Trading Program under which firms are allowed to trade “rights” to emit air pollutants. Outside of the United States, there have been many uses of effluent fees for pollution control, such as the cap and trade policy used in The European Emission Trading System (Wagner, 2004).

Broadly, environmental policy instruments are categorized into three types: command-and-control instruments, incentive-based instruments and a combination of the two, are the most commonly used approaches. The study of these two principal instruments contributes to the regulators’ fundamental understanding of environmental regulation. However, in a context where environmental regulation is becoming the primary approach of environmental protection, economists are seeking a much larger scope of regulatory instruments beyond the conventional

ones in order to avoid the barriers that existing instruments face. They point out that environmental policy instruments are much more than just command and control and incentive-based, rather some economists exhibit some alternative instruments and combination of instruments.

Böcher (2012), in reviewing a large body of literature, concludes that there are four types of regulatory instruments. Identical methods used to distinguish between different regulatory instruments are also applied in Goulder and Parry's (2008) study in order to compare and evaluate a variety of instruments that address environmental policy. The list of instruments includes:

1. Direct regulatory instruments, also known as command-and-control instruments, require the regulator to set up a standard of the amount of pollution one firm is allowed to discharge and the type of control equipment required to meet the goal. For example, there are mainly two types of standards mostly used, technology standards and performance-based standards. The former refers to regulated firms using a specific technology of pollution control, the latter contains a standard but allows firm to choose a way to meet the standard.
2. Incentive-based instruments, such as Tradable Allowance System, effluent tax, subsidy for pollution abatement and tax on inputs or goods related to pollution. They work as an economic incentive to moderate the pollution behavior of firms. This additional price of pollution increases the costs of environmentally detrimental behavior, and as a result, firms tend to seek eco-friendly alternatives to avoid the cost.
3. Informational instruments are interpreted as a movement launched by government or environmental organizations to inform or educate the public by providing consumers with as much information on the product as possible. This can be viewed as a passive approach because little cost is added directly into the production process. For

example, eco-labels printed on less environmentally friendly products such as bottled water may have an impact on purchasing behaviour.

4. Cooperative instruments are operated through a series of negotiation and collaboration, which can be either between the private sector or between the private sector and regulators, which lead to voluntary agreements (VAs) of reducing pollution discharge. This instrument has recently become more prevalent. An explicit overview of such instruments is provided in Section 4.2.
5. Technology policy aims to solve the market failure in the absence of functional environmental instruments by providing more support to innovation. For example, the government uses policies such as enhancing patent rules, increasing subsidies to private R&D and government involved research, to reduce the gap created by market failure.

This list is not exhaustive, as more and more forms of instruments are invented as new or combinations of existing instruments emerge. For instance, the threat of environmental regulation (Cadot and Sinclair-Desgagné, 1996) and training in new technology (Carrillo-Hermosilla et al., 2009) are two instruments that have been studied. The following section will compare and evaluate these instruments.

### **3. Environmental regulation and innovation**

Economists did not adequately establish the relationship between environmental regulations and innovation before the 1970s, when policy makers began to use environmental policies to enforce environmental protection. Many U.S. economists who studied such policies tended to focus on the beneficial effects on society as well as the impact on the industries that are mandated to undertake such environmental abatement standards. For example, one prevailing view among economists on environmental regulations was that “environmental regulations

impose significant costs, slow productivity growth, and thereby hinder the ability of U.S. firms to compete in international markets” (Jaffe et al., 1995, p. 1). The slowdown of the U.S. economy during the same period caused suspicions over whether environmental regulations hurt the competitiveness of the U.S. economy in the long run (Jaffe et al., 1995). This use of cost-benefit analysis to determine an effective environmental regulation received wide acceptance from many economists. Jaffe and Stavins (1995) adopted a similar view in their study referring to environmental regulations as costly standards for firms who are facing challenging competition in maintaining their productivity and competitiveness with firms from other economies that face looser regulations. The loss of cost-efficient production will lower exports and cause a large number of jobs to move to countries with loose regulations over environmental pollution.

In contrast with the view of many economists, Porter and van der Linde (1995) provide an alternative hypothesis, known as the Porter Hypothesis (PH), which suggests a potentially positive impact of environmental regulation on innovation and profit. By claiming that the traditional view underestimated the ability of stringent environmental regulations to generate innovation, and excessively concentrated on “trade-offs” between social benefit and abatement cost, they consider abatement costs as an erroneous interpretation of the problems associated with environmental regulation. They further argue that: “properly designed environmental standards (market-based instrumental in particular) can trigger innovation that may partially or more than fully offset the costs of complying with them” (Porter and van der Linde , 1995, p. 98). This provides a new perspective on the effects of environmental regulation on innovation, which has been further developed in a large body of environmental innovation literature. Notably, two recent research studies (Ambec et al., 2013; Wagner, 2004) review a large body of the PH literature, which provides mixed theoretical and empirical results. However, the positive impact of environmental regulation on generating technological innovation is a common finding.

### **3.1. Overview of the motivations of environmental innovation**

Rennings (1998) defines a “narrow term” of innovations as new technology invention and a “broad term” as first-time application of newly acquired knowledge, new approaches, or new products. The “broad term” also represents a change in organizational structure or the product strategy. Beise and Rennings (2005) further provide a more explicit definition of environmental innovation: “Environmental innovations consist of new or modified processes, techniques, practices, systems and products to avoid or reduce environmental harms. Environmental innovation may be developed with or without the explicit aim of reducing environmental harm” (p. 6). In other words, environmental innovation provides an approach to mitigate the negative externalities from economic activities, through a series of processes including using existing technology or generating new technology (narrow term), and organizational restructuring which integrates more eco-friendly concepts into the production and development of new products (broad term). Some examples of innovations presented in several studies are as follows. First, innovation imposes pollution abatement at the end-of pipe, such as “scrubbers for use on industrial smokestacks or catalytic converters for automobiles” (Leeuwen and Mohnen, 2013, p. 2). Second, innovation adds extra value to commodities produced by the refined production process with the application of new eco-friendly technology (e.g. tissues made by recycled paper). Third, innovation applies technologies “that are targeted to changes in production processes to improve energy efficiency” (Leeuwen and Mohnen, 2013, p. 2). Following most of the literature, this review concentrates on the narrow definition of environmental innovation.

Among studies that attempt to identify the motivation of environmental innovation (e.g. PH) using both theoretical and empirical approaches (Ambec et al., 2013; Wagner, 2004), proxies such as R&D expenditure and the number of environmentally related patents are employed to measure the level of environmental innovation (Jaffe and Palmer, 1997). A vast number of these studies point out that environmental innovation can be motivated by regulatory approaches such as environmental regulations and non-regulatory factors which may include, for example, achieving a first mover advantage in competition (Simpson and Bradford, 1996) and

customer satisfaction (Lyon and Maxwell, 2003). The level of stringency of environmental regulation may also determine the incentives for R&D investment in eco-friendly innovation (Kennedy, 1994; Mohr, 2002) and how firms behave in the context of global competition (Simpson and Bradford, 1996).

### **3.2. Environmental regulation-induced technology innovation: the basic argument**

Of all the theoretical research on the subject of environmental regulation induced technological innovation, Magat (1979) provides one of the earliest evidence on whether different environmental regulation instruments have an impact on the ability to motivate innovation. The study employs a basic model that is used to analyze the induced innovation based on a standard production function. The results show that a technology-based standard barely has any effect on technology innovation compared with three other types of market-based instruments: effluent taxes, pollution permits and subsidies.

Porter (1991) and van der Linde (1995) further on analyze the PH to demonstrate the effect of environmental regulations on inducing innovation and improving business competitiveness. The PH notes that strict environmental regulations (particularly market-based regulations) may induce the use of environmentally friendly technological innovation, which further leads to a more efficient production process. This is called the “innovation effect” which is the main argument of the PH (Wagner, 2004). Different from the traditional cost-benefit analysis of environmental regulation, the PH suggests that environmental regulations may serve the purpose of innovation, of which the investment may be fully or over compensated by the improved efficiency through innovation. To be more explicit, Porter and van der Linde (1995) specify some processes that link properly designed regulatory instruments to innovation. They are:

- Regulation informs firms about the likelihood of resource inefficiencies and probability

of technological improvements.

- Regulation places an emphasis on reducing asymmetric information to raise firms' knowledge of improvement possibilities.
- Regulation lowers the uncertainty of investment compensation.
- Regulation provides incentives to innovate.
- Regulation promotes fair competition among firms.
- Innovation benefit may not always fully cover the cost of compliance.

The core concept of the PH is how environmental regulation can be beneficial to firms. In other words, innovation motivated by environmental regulations may generate benefits, which cover or exceed the cost of compliance. Wagner (2004) provides a further explanation of this relationship, which notes that firms investing in environmental innovation expect to achieve certain objectives, which could be the improvement of product quality or the environment, or in a broader scope, a more efficient production process. Generally, the goal of innovation is to reduce the negative externalities of production and at the same time generate the benefits that exceed the cost caused by the environmental regulation. Additionally, "Reducing waste or converting it onto saleable products also saves on the costs of waste treatment and disposal. Legal expenses and pollution-related fines might also decline as a result of adopting cleaner technologies." (Barton et al., 2002, p. 19)

Given all the benefits pointed out by previous studies, there are still many misunderstandings regarding how environmental regulations affect innovation. First of all, the rationality of the innovation effect is still disputed and may not be achieved in a short period. Porter and van der Linde indicate that, "We readily admit that innovation cannot always completely offset the cost of compliance, especially in the short term before learning can reduce the cost of innovation-based solutions" (Porter and van der Linde, 1995, p. 100). Their studies are mostly based on case studies, which can't be generalized to the entire industry. Secondly, the existence of market failure makes environmental regulations so crucial in terms of the role of increasing incentives for innovation. If firms in a market with imperfect competition consider the regulation standards too stringent to achieve through R&D, they may refuse to comply. Thirdly,

the PH suggests that market-based instruments may trigger innovation, which is consistent with Magat (1979)'s result and the current trend of more market-based and performance-based instruments. Considering these factors, the following section will concentrate on a variety of models used in the existing literature, including several theoretical and empirical researches that are relevant to the topic of regulation-induced innovation.

### **3.3. A review of theoretical and empirical studies**

Although research has established the link between environmental regulation and innovation, it is the PH that has generated a vast body of research concerning the innovation effect of environmental regulation (the weaker version of the PH) (Porter, 1991; Porter and van der Linde, 1995). This is associated with the fact that many regulators and environmentalists would rather consider environmental regulation as a benefit to firms, which often claim that compliance costs are unaffordable. Gabel and Sinclair-Desgagné (1998) suggest that although the PH exhibits a positive relationship between environmental regulation and corporate competitiveness, it is in fact the impact on technological innovations that generates higher profits and increases social welfare. However, upon further examination of their empirical evidence, Porter and van der Linde only provide few case studies to validate their hypothesis, which provides academics with a new research direction to assess these inadequacies.

#### **3.3.1. Theoretical studies**

Since Palmer et al. (1995) criticized the ambiguity of the arguments proposed in the PH using a theoretical approach, the theoretical probing of the argument of the PH has never ceased. Two major directions of research are identified on a broad basis: organizational failure and market failure; both contribute to the barriers between environmental regulations and technological innovation. Organizational failure indicates that although innovation may be a

profitable opportunity, the private sector often ignores it. Clemenz (2012) states that organizational failures are due to “the separation of management and ownership and resulting in principal-agent problems” (p. 2). Market failure refers to market factors such as competitiveness and market size, which reduce the incentive for firms to invest in innovation. Such innovations are often considered a costly and uncertain investment in a competitive market. On a theoretical basis, many studies attempt to examine these two arguments and the results generally confirm the effectiveness of environmental regulations in generating technology innovation.

### **3.3.1.1. Organizational failure**

Organizational failure occurs when firms have a tendency to maintain the technology or behaviour that they are used to, which can prevent firms from innovating as they feel the new technology will increase uncertainty over whether it may generate benefits. Ambec et al. (2013) conduct a survey of a large body of literature with the purpose of reviewing several important theoretical and empirical studies that are related to the main contributions to the PH study in the last 20 years, in which the innovation effect (the weak version of the PH) of environmental regulations is a main subject. Regarding the subject of organizational failure, they conclude that the corporate leader is a critical figure in determining the firms’ investment strategies. The process of making an investment decision can involve many factors such as the leadership style and the consideration of the investment return of short-term and long-term innovation decisions. Clemenz (2012) points to “information asymmetries between owners and managers, but also between different departments inside a firm, creating various principal-agent problems” (p. 5). Many theoretical studies indicate that environmental regulations may, in fact, give more incentives to leaders making investment decisions on innovation and generate more profits, which may be overlooked by the leaders considering the aforementioned organizational failures. For example, Aghion et al. (1997) assume a firm is pursuing a moderate financial strategy, which means that it is financially self-sufficient and has less motivation to embrace costly new eco-efficient technology. Using a theoretical model, the authors then introduce more uncertainty to

firms' financial strategies, such as allowing firms to borrow on financial markets. However, the pressure of generating profit to pay back the debt will force firms to use the newer technology ahead of the others in order to maintain a competitive advantage.

Sinclair-Desgagné (1999) first argues that the neo-classical-economic models does not provide a theoretical basis for the idea of free innovation proposed by the PH, because innovation is considered a cost in these models, and increasing the level of stringency of environmental regulations will simply increase costs and reduce profit. This effect caused by stringent environmental regulation is an organizational failure and it lowers the incentive for firms to invest in innovation. However, the further research by Gabel and Sinclair-Desgagné (1998) specified in more detail this organizational failure assumption, indicating that not all firms suffer from stringent environmental regulation, which may only have a negative impact on firms at a lower stage of technological efficiency, as the compliance cost they have to pay to meet the new environmental standards is much higher than for more technologically advanced firms.

### **3.3.1.2. Market failure and the role of environmental regulation**

Market failure is another major reason why environmental regulations remain desirable. It arises when firms have low incentives to reduce environmentally detrimental activities due to an uncompensated cost of investing in environmental innovation. Beise and Rennings (2005) suggest a type of market failure called the double-externality problem that aims at explaining why firms have little incentives to increase R&D expenditure on innovation. The term double-externality perfectly summarizes the main features of environmental innovation and the barriers to innovation. On one hand, the entire society including innovating firms themselves, benefit from lower pollution discharge (negative externality) generated by a more environmentally friendly technology, while the innovator bears all the cost of R&D. On the other hand, technology spillover, especially when the improved technology is easy to learn and imitate,

makes it even more difficult for innovating firms to realize the economic benefit of investing in eco-friendly technology innovation. In general, three factors may contribute to market failure, such as the “public goods” feature of technological innovations, the negative externality of pollution that is not internalized, and the uncertain social benefit of environmental innovation, which may reduce the benefit of innovation and eventually lead to underinvestment. As a result, in the absence of certain compensation for innovation costs, firms may be unwilling to invest for little or possibly no benefit.

The argument, therefore, is whether regulators are capable of formulating properly designed regulation to stimulate eco-friendly technological innovation given the existence of market failures. Simpson and Bradford (1996) theoretically review this argument using a Brander and Spencer type model of strategic trade policy to evaluate whether increasing the charge of effluent tax can increase the innovation investment in domestic and foreign markets. The results show that under imperfect competition, domestic government may impose stricter environmental regulations in order to help firms maintain a competitive advantage in the international market by expanding the level of innovation investment.

Stringent regulations may also encourage the use of new technologies. Kriechel and Zieseimer (2006) argue that much existing research focuses on the link between the stringency of regulations and the amount of R&D expenditure, rather than the production of technology. To further study this argument, they use a Hotelling approach to explain how levying an adoption tax of new technology on firms (who generally prefer to use old technology) may eliminate the inefficient equilibrium and encourage firms to use new technologies.

Osang and Nandy (2003) propose a different approach to address this argument. They adopt a Cournot duopoly framework with and without government regulation. They find that when the market is unregulated, firms’ optimal choice is to choose the conventional and eco-unfriendly technology. However, this choice of technology is reversed when the government imposes a regulatory policy. This conclusion is consistent with the previous theoretical results (Kriechel and Zieseimer, 2006).

As previously discussed, technology spillover is a cause of market failure when the return on innovation investment cannot offset the expenditure; therefore low emulating costs result in firms underinvesting in innovation. In this situation, stringent regulations may mitigate this problem. For example, Greiner (2003) studies the market failure caused by technology spillover from two markets, one domestic and one foreign. If the firm is facing stricter environmental regulations in the domestic market, competition arises and firms are becoming more aggressive in terms of technological innovation, therefore downstream firms in the foreign market with lax regulations may benefit from technology spillovers from the upstream firms. However, the paper also indicates that cooperation may ease competition among firms and lead to lax environmental regulation. This is because the government often tends to moderate the level of competition by reducing the stringency of regulation.

### **3.3.2. Empirical studies**

There has been an exceptionally large amount of literature focusing on the empirical analysis of the effect of environmental policy on innovation. As a weaker version of the PH, the argument of environmental regulations inducing innovation that will eventually compensate the compliance cost is widely accepted by economists (Clemen, 2012). However, there are still obstacles of how to correctly measure the level and intensity of induced innovation with existing data facing economists (Jaffe et al., 1995). Jaffe et al. (2002) suggest that an acceptable method is to analyze the link of innovation to the shadow price of environmental regulations, but this is not feasible in practice. Thus they recommend using proxies of both innovation and regulation instruments, such as environmental R&D investment and effluent tax. We observe that many of the existing empirical studies use such an approach.

Notably, Jaffe and Palmer (1997) provide the first-hand empirical analysis of the PH. The authors examine the relationship between pollution abatement expenses (a proxy for the stringency of environmental regulation) and measures of innovation activities such as the amount

of R&D investment. The results show a positive relationship between abatement expenses and R&D investment. However, this paper fails to find a significant relationship regarding environmental regulations and the number of applications of innovation patents generated. This result is in contrast to Lanjouw and Mody (1996), who find a positive effect of environmental abatement costs on the number of patents of eco-technologies. They further suggest that market-based instruments, which create more benefits and new eco-friendly technologies, should be preferred to command and control instruments.

Other research to proxy technological innovation with the amount of new patents also demonstrates a positive effect. Popp (2003, 2006) uses solid empirical research to show the positive effect of regulation on the amount of new environmental technology patents. He performed empirical analysis aimed at examining the effect of the number of applications submitted before and after the 1990 Clean Air Act in the United States, which set a trading market for SO<sub>2</sub> emission permits (market-based instruments). The results show that market-based regulations create higher incentives for technological innovation than the previously used command-and-control regulations. Popp also praises the use of market-based regulatory policies to stimulate technological innovation.

Another empirical study by Böhringer et al. (2012) based on a panel dataset including 23 manufacturing industrial sectors of Germany between 1996 and 2002 aims at exploring how clean technology investment affected the German manufacturing industry. The paper starts by proposing the arguments between pro green-technology transition and the concerns of implementing new environmental policy. Supporters of the Green New Deal regulation anticipated more investment in environmental friendly technology that would move the country toward a low carbon economy with less fossil energy resource use. Those concerned questioned whether new technology would increase the cost burden of the manufacturing industry, reduce productivity and further hurt the competitiveness of German production. In light of these concerns, the results show that increasing environmental investment generates an increase in German production due to innovation, which leads to increases in productivity. The conclusion drawn from this research is that environmental regulation could generate incentives for firms to

invest in technological innovation to ameliorate firms' environmental performance and secular economic growth (Böhringer et al., 2012).

However, one deficiency is that previous studies are built on industry level data rather than firm level data, and some economists consider firm level data better serves the empirical research of the innovation effect on regulations. For example, in a recent study, Leeuwen and Mohnen (2013) argue that the current dataset is not adequate for the empirical research on the PH to explain how certain regulatory instruments may provide incentives to technological innovation at the firm level. Their empirical paper using data from the Netherlands collected from 2000 to 2008, examines the weak version of the PH to test the impact of environmental regulation on environmental innovation and total factor productivity. The model is widely used for studies with only firm level data rather than data from the entire industry. The results confirm the weak version of the PH, concluding that government regulations strongly influence firms' investment in R&D, especially in environmentally friendly technologies and innovation. In general, both theoretical and empirical studies have found evidence of a positive relationship between environmental regulation and innovation, also known as the weak version of the PH.

Recently, several studies have expanded their scope to a more specific aspect of the innovation effect of environmental regulation. An important question is how to implement the correct environmental policy on a certain type of technological innovation. For example, Johnstone et al. (2010) suggest that "tradable energy certificates are more likely to induce innovation on technologies that are close to competitive with fossil fuels" (p. 1). In the context of the prevalent use of alternative energy to replace conventional energy, many countries are undergoing a transition to using an increasing percentage of renewable energy in their total energy consumption. Johnstone et al. pay close attention to this market in an attempt to test if the innovations of renewable energy are affected by the related environmental policy. Their study found a positive effect of R&D incentive policies, which encourage the development of renewable energy. One additional substantial indication for the policymaker found in this research is the choice of policy instruments used to incite innovation. This will be discussed in the following section.

## **4. Choosing environmental instruments and the impact on innovation**

An increasing variety of environmental policies present a challenge for economists. Empirical research has concluded that, on the whole, environmental policies can affect innovation of eco-technologies in almost all aspects (Carrillo-Hermosilla et al., 2009). A crucial question for policymakers to consider is whether regulators can design and implement *one* strong and cost-efficient instrument that works effectively in generating eco-technology innovation.

The objective of this section is to demonstrate how policymakers use criteria to formulate a policy instrument to most effectively generate environmental innovations to mitigate the environmental burden at an affordable cost. In other words, a good environmental policy should be able to generate most benefits on both social welfare and profits, and also contribute to the innovation of eco-friendly technology. For example, the famous SO<sub>2</sub> allowance-trading program as part of the 1990 Clean Air Act Amendments is considered one of the most effective environmental programs (see Chan et al., 2012).

### **4.1. An overview of the effectiveness of traditional policy instruments**

Many authors have discussed and compared the effectiveness of a variety of environmental instruments on generating more technology innovation. A majority of them compare two conventional instruments, namely, command-and-control and market-based instruments. The environmental effectiveness of the former type can be defined as whether a predetermined environmental goal can be achieved by implementing such instruments, and the latter one is evaluated as “triggering static and dynamic efficiency and internalizing environmental externalities in and between markets” (Leeuwen and Mohnen 2013, p. 4).

Command-and-control instruments are less effective in terms of motivating technological innovation than market-based instruments (Popp, 2003). Many authors hold mixed opinions regarding the effectiveness of command-and-control instruments as an incentive for innovation

(Magat, 1979; Jaffe et al., 2002). An earlier study conducted by Magat (1979) uses a theoretical approach that aims to find the discrepancies between five different types of environmental regulatory instruments, which focus on inducing technology innovation. Magat employed a dynamic model, noting that the command-and-control instruments provide the weakest incentives for innovations compared with the four other instruments, including market-based instruments.

Market structure also contributes to part of the disparities among differing instruments in terms of their conductivity to innovation, especially among market-based instruments. Requate (2005) concludes that emission taxes may perform better than tradable permits in a competitive market given that regulators are short sighted. After reviewing 28 models regarding the incentives of emission taxes and trading permits on R&D investment, he finds that emission taxes are more effective in terms of encouraging R&D investment. He also studies the application of eco-friendly technological innovations compared to permits, whose prices tend to fluctuate due to their market features, which may have a negative impact on the willingness of firms to invest in eco-technology innovation. Kemp and Pontoglio (2011) also observe that the effect of market-based instruments on innovation is not as strong as they expected, which is relatively consistent with Requate's conclusion.

Monero (1998) thoroughly explains how market structure determines the rank of the instruments in terms of the incentives to innovate. He compares the incentives for innovation among five environmental instruments, consisting of emission standards, tradable permits and so on, in the context of a market with different structures. Requate (2005) reviews Monero's research and concludes that "for imperfect competition on both markets (output and permit market), ... an emission standard ... provide(s) a higher incentive to invest than free permits" (Requate, 2005, p. 185), which demonstrates a situation in which command-and-control instruments may be more effective in generating innovation than market-based instruments. This conclusion is consistent with Malueg's (1989) research, which identifies weakness in the effectiveness of market-based instruments in all circumstances.

The previous discussion has focused on the incentives of firms undertaking R&D investment in eco-innovation under different instruments of environmental regulations. There is no consensus on the ranking of the effectiveness of instruments, which depends on several factors, such as different market structure, the size of the market, and the level of competitiveness.

## **4.2. Voluntary Programs**

Voluntary instruments exist when firms make a commitment, which surpasses the existing regulations of environmental policies and law in order to improve their environmental performance. These instruments have been gaining increasing attention as a new method of environmental regulation since the 1990s. Voluntary instruments contain more features that distinguish them from command-and-control instruments. First, the government is no longer the only party that offers support with information and subsidies, as firms' shareholders and consumers would also provide incentives to incite environmental innovation. Second, the stringency of environmental standards differs across programs, which gives firms more flexibility to strategically choose which program suits them better (Arora and Cason, 1996).

Firms that participate in the voluntary programs tend to exhibit their efforts of environmental innovation to their shareholders and consumers, which is often considered a process of branding image. Lyon and Maxwell (2003), using the method of classification from the European Union Research Network, describe three main types of voluntary instruments: Unilateral Commitments, Public Voluntary Schemes, and Negotiated Agreements. Different from traditional approaches, the voluntary approach has many advantages in terms of low legislative costs and low compliance costs. Voluntary instruments are an efficient new environmental regulatory policy that is increasingly adopted by regulators. Voluntary instruments are ultimately incentive-based; they work when polluting agents are self-motivated to innovate in order to receive financial subsidies and obtain customer satisfaction without the

threat of regulations, which together provide an incentive for firms who would pay a higher price for their enhanced environmental efforts (Arora and Cason, 1996).

Identifying the motivations to participate in such voluntary programs is an important step to understand how voluntary instruments work and why they are effective in generating eco-friendly technologies. First, the polluting firms' rationale of complying with environmental regulations may determine how policymakers should choose effective environmental instruments. Particularly given the increasing number of firms that are actively involved in the environmental protection program, voluntary instruments might be a primary choice for regulators. Second, environmental protection programs are more than just a framework implemented by regulators, they are also a business opportunity to invent and trade eco-friendly technologies among both existing large corporations and entrepreneurs, who are most actively involved in environmental innovation. Third, Consumers are increasingly ready to pay a higher premium to purchase eco-friendly products, such as the electric automobile. These aforementioned motivations may have a substantial impact on the formulating process of environmental policies, particularly the voluntary instruments, which should be understood and examined carefully (Hemmelskamp, 2000).

Economists have thus far provided inadequate empirical evidence regarding the impact of this new policy instrument on innovations, due to several factors, including the lack of data collected under the existing voluntary programs for research purposes (Lyon and Maxwell, 2003). Most of the existing studies in this area agree upon the positive effects of voluntary instruments on environmental innovation. Generally the relationship is examined through the proxies of the motivation side of innovation. For example, Arora and Cason (1996) explore the incentive from the extent of consumer contact, which is proxied by commercial cost. They argue that firms with a higher level of consumer contact are more likely to join the voluntary programs to increase their environmental performance, in which case consumers' environmental expectations determine the effectiveness of such programs. The result of their study is consistent with this presumption. Using data collected under The EPA (U.S. Environmental Protection Agency)'s 33/50 Program, including a series of voluntary programs the goal of which is to

reduce the releases and transfers of 17 toxic chemicals by 33 percent before 1992 and 50 percent before 1995, the authors prove that large corporations with large-scale consumer contact are more actively involved in voluntary programs.

Corporations that are willing to overcome the existing environmental laws and regulations, are recognized as eco-friendly organizations by their consumers as well as their shareholders, who value such environmental efforts as a business opportunity (Prakash and Potoski, 2012). Yet, such efforts may be associated with concerns that large corporations with superior capabilities can generate environmental innovations and may take advantage of such voluntary programs in order to gain from governmental subsidies and to achieve a competitive superiority in environmental performance, as will be discussed in the next sections.

### **4.3. Main factors of policy instruments to be considered**

Formulating an efficient and effective environmental policy is a complex process. Regulators must take into account many factors together with reducing environmental pollution. Technological innovation is undoubtedly one of the many factors that contribute to the success of a policy, and perhaps the most important standard, since technological innovation provides a more efficient method of both cost saving and environmental protection. Carrillo-Hermosilla et al. (2009) specify 19 factors that an effective environmental instrument should contain to promote technological innovation. Given that a thorough and comprehensive analysis of these factors is presented in their research, the following discussion will provide a brief summary of their analysis.

First, regulators ought to understand the obstacles in technological innovation while formulating an environmental policy. As mentioned in Section 3, organizational failure and market failure are two central reasons that prompt the need for regulations. A third failure to be considered is from the government, due, among other things, to bureaucracy and asymmetric

information. Carrillo-Hermosilla et al. (2009) identify these failures from two aspects: inside and outside of the firm. For example, from the inside, a firm competing globally can usually afford to integrate all of its resources to R&D investment for better eco-technology. As discussed, such firms may be active participants in technological innovation or it may be a hurdle to such innovation if they are competing in an oligopoly market. From the outside, factors such as consumer push, financial institutions, competitors and suppliers may also affect environmental innovation and technology implementations. As firms face differing obstacles, regulators must design specific combinations of instruments depending on which objectives they want to achieve (Carrillo-Hermosilla et al., 2009).

Second, the use of mixed environmental instruments may cause some potential concerns over whether certain interactions between instruments may not be effective in providing incentives. This is due to the different focus of instruments on either environmental protection or technology innovation, which require a better collaboration between both policy instruments for different purposes (Carrillo-Hermosilla et al., 2009).

Third, in many situations, regulators ought to acknowledge that regulations might lead to failures such as developing an undesirable technological innovation or a regulation that is implemented in a sector that does not require regulation for innovation incentives. One of the key reasons for such failures is due to the use of wrong information in the formulation of policy since current technology does not necessarily reflect the direction of the technology trend, which can lead to erroneous technological innovations (Carrillo-Hermosilla et al., 2009).

Fourth, regulators must consider the innovation process with interactive phases that consist of invention, innovation, and diffusion, without a sequential order. In other words, these three phases may occur simultaneously and have a mutual impact on one another. Although the focus of this paper is on the innovation of eco-technology, which is only considered as one phase of technology innovation, the other two sides are also substantial in the process of creating effective environmental policy. Therefore, regulators should not apply a “one-size-fits-all policy approach” (p. 56) on all phases of innovation (see pp. 52-70 of Carrillo-Hermosilla et al. (2009) for details).

There are also other factors that should be considered by regulators when developing new policy instruments to foster technology innovation. For example, it is important to determine the stringency of instruments for radical technological innovation. A policy with a thorough evaluation process concerning all of these important factors may provide more sustainable and long-term incentives to eco-innovation (Carrillo-Hermosilla et al., 2009).

#### **4.4. The evolution of regulatory instruments**

Another research trend concentrates on innovation efficiency with respect to the diverse characteristics of new environmental instruments, given that these instruments continue to evolve as do concerns over widely used traditional instruments. For example, Rennings (1998) presents a few challenges to traditional instruments. First, in contrast with the traditional view that market-based instruments perform more effectively in generating innovation than command-and-control instruments, command-and-control instruments combined with the renegotiations of voluntary agreements at the end of each phase of development, may increase the efficiency of innovations. Second, political influence may lead to a lower tax on pollution, which will reduce the innovation efficiency of market-based instruments. These distortions of traditional environmental instruments thus lead to evolutionary instruments. Tradable emission is a policy that combined the features of both market-based and command-and-control instruments, and is favoured in terms of innovation efficiency. A pertinent example of this policy is the U.S. SO<sub>2</sub> allowance-trading program, included in the 1990 Clean Air Act amendments (Rennings, 1998).

In addition to the traditional instruments and their combined forms, other environmental policy instruments such as informational instruments, cooperation instruments and technological instruments are highly accepted by regulators today owing to their advantages, which allow them to fit into a certain regulatory objective. For example, government programs targeting R&D provide both public and private sectors with financial support, which aims at partially covering the cost of innovation and application of new technologies. During the early period of the new

technology, such support may often mitigate the lower incentives caused by double-externalities, as described in Section 4.5. Another example is “foresight exercise” (Carrillo-Hermosilla et al., 2009) which aims at helping industrial sectors form a long-term perspective of where technological innovations are moving. One crucial factor of such an instrument is to integrate knowledge and information from various parties which are involved in the innovation process, such as industrial sectors, regulators, and research agencies. The idea of this joint partnership is to identify a successful technology from its early stage and foster it until it reaches fruition. Considering the potential failure of government aid by choosing the wrong technology to support, using a foresight exercise may reduce the risk of the government advancing such failures. For the purpose of eco-technology innovation, traditional environmental regulations increasingly consider the idea of technological instruments in policymaking, which may overcome more obstacles that were between environmental regulations and innovation (Carrillo-Hermosilla et al., 2009).

#### **4.5. Policy instruments for environmental innovation: different types of innovation**

Does environmental innovation differ from other forms of technological innovation? Does it require a specially designed policy to motivate a certain type of environmental innovation? As discussed in the previous section, environmental regulations should be mixed with some features of technology regulations in order to best promote technological innovation; the collaboration of instruments must be dynamically used in all phases during the innovation process. There are three main issues in this argument that are related to environmental innovation: double externalities, the driving force (technology driver or demand driver) and social change (Rennings, 1998). The consideration of these issues helps to overcome market failure by formulating a special policy for environmental innovation and also helps to better understand which instrument is more effective in generating a certain type of innovation. For example,

Carrillo-Hermosilla et al. (2009) specified several types of innovations to explain how different instruments fit into the needs of each innovation type individually.

The first difference is the maturity of a new technology, which is frequently related to the phase at which the technology has been developed. In regards to the aforementioned three phases of innovation, a less mature technology typically remains at the earlier phase of innovation, and normally requires more efforts in order to be successfully developed. Thus, more stringent governmental regulation, vast R&D investment, and information support from the government are effective instruments in stimulating innovation. However, a mature technology, which has already been a success in the market for adoption, does not need as many governmental subsidies and regulations, but relies more on consumers' demand and shareholders' interest (Carrillo-Hermosilla et al., 2009).

The second difference lies in how quickly and drastically technology changes. Incremental innovations often require less effort and production costs, and they are not as difficult to achieve. Therefore, if correct informational instruments are used, the technological innovation is achieved effectively without stringent regulations. On the contrary, radical innovations require more resources from firms, such as enormous R&D investment and great support from inside and outside of the firms, without which firms are generally less willing to engage in such radical innovation efforts. Therefore, regulators are required to not only formulate stringent instruments to create more incentives, but they also need to provide a vast amount of support to keep firms motivated in the innovation process (Carrillo-Hermosilla et al., 2009).

## **5. Policy instruments and innovation: industry studies**

### **5.1. The clean energy industry**

Environmental regulation has a significant impact on the innovation of renewable (clean) energy technology, such as solar power and geothermal heat. The International Energy Agency identifies three stages (development, application, and diffusion) to describe the development of renewable energy technology, which demonstrate that clean technology is undergoing fast development and moving forward to large-scale application globally (Johnstone et al., 2010). This also creates a new business opportunity in the market where cleaner technology can be purchased and applied by both industrial leaders and foreign countries. The export of technology may therefore compensate the cost of R&D for technology innovators and patents holders. Firms, other than the polluters, also may have an incentive to innovate in not only pollution control but also in pollution prevention. Thus there are two industrial sectors that are driving the progress of renewable energy, including large corporations and entrepreneurs (Georg, 1992).

An analysis of the polluting firms' need for clean technology innovation certainly may provide valuable knowledge toward the dynamic efficiency of the various instruments, given different market conditions and information structures. For example, Georg (1992) focuses on the role of governmental subsidies in supporting the development of clean technology innovation. He argues that in addition to being a subsidy provider, the government should also be an information provider, assisting firms in finding the right technology for innovation and giving informational incentives. This is another key example of how environmental regulations can be combined with other instruments to maximize innovation efficiency. The commercialization of clean technology innovation is in the earlier phases of development and thus remains a work-in-progress. It requires substantial governmental support in many forms, such as financial subsidies and informational guidance, to help promote technological innovation to a higher level of the development hierarchy. Considering the vast business opportunities it stimulates, governmental supports thus accelerate the progress of innovation. Also, from the demand side, clean energy

technology is widely accepted amongst consumers and shareholders as a replacement of fossil fuel, and therefore, regulations do not need to be stringent to motivate clean technology innovation (Georg, 1992).

Solar energy is emerging as a booming industrial sector because of the high emission of fossil fuels. In spite of its rapid growth (30 to 35% per year), the solar energy sector is still marginal, representing only between 3 and 6% of total installed electricity generation capacity by 2020 (Lorenz et al., 2008). But the growing popularity of solar energy creates more opportunities for existing firms that need sustainable but cost-efficient energy resources for production. Those firms are more inclined to invest in the improvement of solar-cell designs and the manufacturing process, to bring new solar energy technology into the market in order to increase competitiveness. Government policies continue to have an impact on the future of this emerging industry. California, with some of the highest electricity prices in the United States, has been experiencing an increasing trend of use of solar power in the face of rising cost of fossil fuels and because governmental subsidies drive the cost of solar power lower than conventional utilities. As a result, the increasing demand of conventional electricity continues to increase the cost of traditional electricity as natural gas prices, which are driven by the government's environmental policies, rise. This provides a good example to explain the effect of how governmental regulations can encourage the clean energy sectors and at the same time make this new technology more affordable (Lorenz et al., 2008).

To effectively regulate a clean energy industrial sector, there are several factors regulators must carefully consider before making a decision. First, regulators must specify the objectives of regulatory instruments and set up priorities in their execution. For example, is the solar energy industry a policy that aims at reducing emission discharge, creating new jobs in the solar energy industry, or keeping the economy robust by encouraging new technological innovation? Having the answers to these questions may create a clear perspective for firms. Second, regulators must subsidize cost-efficient production. Firms that generate the most solar energy are not necessarily capable of maintaining their competitiveness in the long term. However, those with cost-efficient technologies are able to drive solar energy prices lower than conventional electricity. Lastly,

considering that solar power has not yet become as cost competitive as conventional electricity, governmental subsidies are still required. However, these supports should eventually phase out when there is no price disparity between solar energy and conventional electricity (Lorenz et al., 2008).

The development of clean energy is regarded as a threat to the conventional energy industry, such as natural resource firms, which tend to use their political power to influence this industry's progress. Therefore, regulators should take this into account and carefully evaluate the political feasibility of a new environmental policy targeting the clean energy industry. One example of the powerful influence of the conventional energy industry (mainly the coal industry with many lobbyists in the Social Democratic Party of Germany) are the political obstacles that the policies of advocating use of renewable energy sources, faced in Germany since 2000 (Bechberger and Reiche, 2004).

## **5.2. The natural resource industry**

For a long time, the natural resource industry has been regarded as generating lots of negative externalities. Given the fact that many countries' economies are highly dependent on the use and exploitation of natural resources, the natural resource industry must be more careful and requires strict regulation because of its unsustainable characteristics and due to the irreversible environmental damage caused by exploitation. The issues for many regulators are therefore to acknowledge the position of exploitation and whether the technologies used during this process are sustainable. Policy instruments should be designed with these questions as well as a long-term perspective of environmental protection (Coria and Sterner, 2011).

Coria and Sterner (2011) review the policy instruments used in the natural industry and the impact on sustainability of natural resource exploitation. One distinct feature is the wide use of mandatory regulation such as performance standards and technology standards. Under the

regulations of technology standards, firms are highly restricted in choosing technologies and not encouraged to develop less costly exploitive approaches. On the contrary, performance standards encourage certain types of solutions over others, which results in a technology prejudice as one technology may be preferred by regulators to the others. Overall, environmental regulations of the natural resource industry do not provide adequate incentives to technology innovation. This may be related to the many challenges that this industry faces. They argue that the existence of political infeasibility, market conditions and a lack of professionals in many countries may contribute to less motivation for technological innovation. For example, many lobbyists and labour-intensive firms may not always welcome the optimal technology choice, since eco-friendly and cost-efficient production is often associated with the loss of lower-skilled labour jobs, which regularly carry heavy political support.

## **6. Strategic use of innovation**

The vast majority of the regulation-innovation literature is focused on regulations that induce innovation but not on how technological innovation might induce government to ratchet up or down the stringency of regulations. Accordingly, this section reviews some studies and examples of this issue. In a market with imperfect competition, government regulations often provide many incentives to firms to invest in eco-friendly technology innovations, which is well documented in the previous sections. In a normal case of regulation-induced technology innovation, regulators use a prescriptive standard or set a new level of technology that no firm in the market can meet without large R&D investments. As a result, new, cost-effective technology is invented through regulatory encouragement of innovation. However, firms may behave strategically under environmental regulations in some situations. Puller (2006) explicitly describes one such situation:

“If for some reason the industry does not innovate, the regulator would have an incentive to ratchet down the regulation to avoid imposing an expensive policy on society. This will create incentives for the firms in the industry to behave

strategically with the regulator when choosing innovation” (p. 690).

An alternative explanation of this strategic behaviour is to perceive this situation as how firms are coping with the new regulatory standards. For instance, a stringent impetus of compliance proposed by a regulator would accelerate the action process of innovation inside firms that are able to excel in the new technology standards and to create competitive advantages by ratcheting up the regulatory standards. Also, “firms may reconsider developing [...] capabilities if this may result in policy types that they would not prefer” (Fremeth, 2009, p. 37).

A theoretical study conducted by Puller (2006) provides two conditions where firms may behave strategically: firms operating in an oligopoly market, and regulators with no intention of making a commitment to meet specific regulatory standards. Under this circumstance, whether or not firms choose to innovate for compliance wholly depends on their operational strategy and their capabilities. Firms have two decisions. They can choose not to innovate if there are fewer incentives in the market to do so, given that the regulation standards are expected to increase and the regulated firms have no cost advantage. They may also choose to innovate and urge regulators to ratchet up regulations, so competitors who have no cost advantage will be squeezed out of the market. However, the cost of innovation must be compensated by the benefit from achieving the first mover advantage, which is determined by how much cost will be raised for the rivals and whether the gap between the new innovations and the original regulatory standards is large enough that the rival firms become less competitive. The results show that in an oligopoly market, firms with lower marginal costs of innovation have an incentive to invest in environmental innovation to increase the regulatory standards and thus raise rivals’ costs (Puller, 2006).

Some economists argue that the introduction of stringent environmental regulations will consequently cause the market to become more concentrated to a limited number of oligopoly players, which will discourage competition. This is indicated by Montero (1998), who uses a firm-level study to compare innovation incentives caused by five environmental policy instruments including both command and market-based instruments. He concludes that

instruments' "comparative advantage lies on factors such as the initial allocation of permits and standards, heterogeneity of an industry's innovation opportunities, and industry size" (Montero, 1998, p. 6). In other words, large corporations may carry many advantages such as sufficient funds, plentiful R&D investment, numerous patents, and so on, in competing with other competitors. All of these advantages can be transferred into cost-efficient production under environmental regulation, which acts as a barrier and reduces competition. Eventually, this will become a new incentive for large firms to lobby for tougher regulation in order to achieve an oligopoly role as a market leader (Montero, 1998).

A representative case for this argument is how DuPont reacted to The Montreal Protocol (MP), which required a gradual reduction of the use of chlorofluorocarbons (CFCs) during the 1990s. Before the MP, the market in which DuPont existed was somehow competitive with two major corporations playing the leading roles and several small firms, which were quickly becoming strong competitors. Rather than a threat, the arrival of the MP turned out to be a great opportunity for Dupont to regain its lost market share. The increasing investment in R&D of an alternative product to CFCs is a persuasive example of a corporation's strategic use of regulation to enhance its competitiveness. In the end, the MP became one of the most effective environmental regulations in history in terms of the number of CFC replacements Dupont invented through use of its advantages in R&D. Dupont therefore reinforced its leading role in the market and successfully persuaded the regulators from the United States and Europe to increase the stringency of the MP to an even higher level (Puller, 2006).

Until now, the discussion in this paper concerned firms competing in the same market under the same stringency of regulations and strategic decisions made by firms in response to the regulations depended on the domestic country's internal factors. However, when domestic firms are competing with foreign firms, the stringency of regulations should also be valued properly in the process of strategic decision-making. Nehrt (1998) suggests some factors that may help firms who attempt to maintain the first mover advantage in a market where they are facing competition from foreign competitors with less stringent environmental regulations. Firms must maintain their comparative advantage and keep their costs competitive, including the compliance cost of

more stringent domestic regulations. This is based on the assumption that more demanding environmental regulations will universalize in the long term, which means all firms will eventually have to bear the cost of meeting similar environmental standards. The paper concludes that firms headquartered in a country with tougher environmental regulations will maintain a competitive advantage over their counterparts. The study further suggests that firms put more efforts into the innovation of eco-friendly, cost-efficient innovation, rather than to persuade the government to ratchet down the stringency of regulations.

## **7. Conclusion**

The main objective of this paper was to explore the fundamental relationship between environmental regulations and innovation (particularly technological innovation). Partially suggested by the Porter (1991) and van der Linde (1991, 1995) as the weak version of the PH, the innovation effect of environmental regulation is examined by a large body of literature, among which several theoretical and empirical studies were highlighted and reviewed. In general, the results theoretically suggest a positive effect between the stringency of regulations and the progress of technological innovations, given the existence of barriers (internal or external) that firms face such as organizational and market failures. Empirical studies, elsewhere which use both industry-level and firm-level data, also find some evidence of the positive effect on innovations, which are proxied by various variables such as R&D expenditure and the number of environmentally related patents.

Acknowledging this positive relationship, the paper advanced to explore the effectiveness of different types of regulatory instruments in generating technological innovations. After a short overview of the comparison of conventional regulatory approaches, which indicated that market-based instruments, with a few exceptions, generally have a superior performance in generating technological innovations than command-and-control instruments, the paper examined the effectiveness of a few emerging regulatory instruments. Voluntary instruments are featured in

the discussion of the development of new policy instruments, which is considered as a new trend of environmental regulations that increasingly focus on cost-efficiency and effectiveness in motivating technological innovation. This paper also discussed how to implement the correct policy instruments and their degree of stringency on the targeted innovation.

Several conclusions were made throughout the discussion. Notably, tough regulations with informational support from the government should be used to stimulate the innovation of a technology in the development phase. On the other hand, governmental subsidies and stringent regulations work effectively in generating radically technological innovation. Lastly, two industrial sectors (the clean energy industry and the natural resource industry) were highlighted in the discussion of how governments should regulate environmental performance in different industrial sectors considering factors such as political background, market competition and industrial characteristics. The last section of the paper discussed how firms strategically use environmental regulations to achieve certain competitive advantages. This implies that, in some markets with imperfect competition, firms with advantages in technology and capital tend to actively participate in innovations in order to force the less competitive firms out of the market.

Finally, the paper has provided a survey of several important studies of the relationship between environmental regulation and innovation, which generally demonstrates the positive effect of regulation on innovation. Especially and more importantly, this paper provides an initial attempt to explore the effectiveness of evolutionary instruments of regulation on innovation and places them in the context of different types of innovation, which provides a direction for future empirical research, which has not been adequately studied due to the difficulty of collecting data in this area of research. The conclusions drawn from the literature surveyed point to differences among industrial sectors as important factors for policy makers to consider when formulating and designing policy instruments.

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