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Essays On The Effects Of Environmental Policy On Technological Adoption

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Chapter 1

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Chapter 2

Introduction

This dissertation presents three essays on the effects of the economic incentives granted by the environmental policy and particularly, the economic incentives for technological adoption. The first essay, "Environmental Policy and The Diffusion of a New Technology", studies the impact of the choice of policy instruments on the timing of investment in an environmentally friendly technology from a theoretical standpoint. The second essay, "Environmental Policy and the Timing of Technological Adoption in Santiago, Chile: The Natural Gas Case " takes an empirical tack, analyzing the impacts of the Chilean environmental policy on the timing of switching to a cleaner fuel. In the meantime, the third essay, "Transactions in The Santiago Emission Market: ¿Why did sources lost their emissions rights?" evaluates the performance of the compensation system for particulate matter applied in Santiago, describing the transactions that have taken place until now, the obstacles that the system has faced and how it has reacted to new regulations and market conditions.

The three essays share in common the application of economic analysis to issues in environmental policy, addressing both optimal policies in theory and the effects of actual environmental policies in practice. The first two essays address fundamentally dynamic issues in environmental policy, dealing with how environmental policies shape the path of technological adoption over time, while the link between the second and the third essay is the analysis of the economic incentives granted by the Chilean environmental policy

"Environmental Policy and The Diffusion of a New Technology"

It has been well documented in the literature of technological adoption that one of the central features of the diffusion process is the apparently slow speed at which firms adopt new technologies. As a matter of fact, the time path of adoption typically follows and S-curve, where a period of relatively rapid adoption follows an initial period of slow taking off and precedes a late period of slow approach to satiation.

If a new technology is a significant improvement over existing technologies, it is important to ask why some firms adopt earlier than others and which policies may help to accelerate this process. This is specially true in the environmental field, where much of the adverse impacts of many technologies currently in use, could be reduced bringing into use more environmentally friendly technologies. In fact, policymakers usually have a wide range of policy options to affect firms´s behavior, so it is worth understanding how environmental policy instruments than implicitly or explicitly increase the economic incentives to reduce emissions, affect the diffusion rate of these technologies.

This question has been analyzed partially by many researchers, leading to the generation of different rankings that tend to support the use of market instruments over command and control policies, but with little agreement about the supremacy of a market tradable permit system over an emissions tax. Most existing studies explore the adoption under a static framework and hence, have been unable to study the dynamic aspects behind adoption that can give account of the diffusion´s graduality, missing the impacts that one firm´s decision could have over its rivals. This paper is an attempt to include such elements and analyze how they can alter existing instrument rankings. Specifically, the essay explores the effects that the strategic interaction on the final product market has over the profitability of adoption of heterogeneous firms that learn about the scope of the new technology through sequential adoptions.

In the model, the only production cost is related to the fulfillment of the environmental policy. Current abatement costs are heterogeneous. A new technology that allows all firms to reduce the abatement costs becomes available and firms must decide their optimal date of adoption. Without loss of generality, firms can be ordered according to their adoption benefits starting from the firm with the highest abatement cost to the firm with the lowest abatement cost. Under rivalry in the final product market, a firm´s pre-adoption profit as well as its post-adoption profit may depend on the number of adopters, and the adoption incentive for firms higher in the adoption order can be larger or smaller depending on the differentials in these profits. A firm´s incentive to adopt may introduce an incentive for preempting adoption of rival firms, thus speeding up the timing of adoption.

On the other hand, the rival´s adoption can benefit the remaining firms since the value of the investment required to bring into use the new technology decreases with the number of firms that have adopted. Thus, each firm must decide its timing of adoption weighting the benefits and costs of delaying the technological upgrade.

This very simple model of adoption, seems to capture much of the essence of the problem, producing a sequence that is "diffused" into the industry over time. Then, it is possible to determine how different policy alternatives can alter the sequence.

Each policy instrument produces a different value on the differentials in the pre and post adoption profits. The one that induces the largest difference for the early adopters will encourage the earliest timing of adoption since the cost of adoption decreases faster when a considerable fraction of firms have adopted. So an early adoption of the former make more profitable an early adoption of the last.

Policy instruments impose restrictions over firms, who must maximize their profits subject to such restrictions. An emission tax or a tradable permit system impose a price over emissions, leaving to the firms the problem of determining the optimal mix production-emissions. Since in the model the only production cost is the cost of satisfying the requirements posed by the regulator, the higher the tax or the price of the tradable permit, the lower the quantity produced. Instead of setting a price, an emission standard restricts the maximum emissions allowed, restricting therefore the maximum level of production. The adoption of a new technology, that reduces the abatement costs, creates then different sources of benefits depending on the policy used, since it allows firms to reduce the adverse impacts of the restrictions imposed over them.

Two main sources of benefits arise from technological adoption in this framework: - the savings due to the lower abatement costs and - the profits due to an increase in the optimal level of production. Firms always will enjoy of the flow of savings due to adoption, although the size of these savings will depend on the instrument selected. More specifically, an emission standard and the tradable permit system will also give firms a flow of profits due to the additional production that becomes profitable because of the reduction in the implicit cost.

An emission tax will produce considerable savings on the abatement cost while the incentives to produce remains unchanged since the tax, that corresponds to the implicit production cost, does not change over time. An emission standard will produce lower savings on the abatement cost while the optimal level of production increases the most. Finally, a tradable permit system produces lower savings in the abatement cost than the tax and lower profits than the emission standard for a firm deciding whether or not to adopt.

The relatively poor performance of the tradable permit can be explained by the price endogeneity. As soon as a firm adopts the new technology, the market price of the permit decreases because of the decrease in the emissions´s demand. This encourages all firms to increase their level of production, which under rivalry in the final product market reduces the fraction of profits that the adopter can take capture. At the same time, the decrease in the permit price reduces the profitability of additional abatement, making the savings lower.

Numerical simulations of the adoption´s flow of profits show that the tax produces the earliest adoption pattern, followed by the emission standard and by the tradable permit system. However, the pattern of adoption induced by the emission tax does not produce the highest social welfare since the decrease in the abatement cost does not benefit consumers. In the meantime, the emission standard and the tradable permit system foster adopters to transfer the lower abatement cost into higher production, improving consumers ´s welfare. Nevertheless , as it takes so long to the tradable permit system to encourage adoption, the emission standard is the instrument that improves the present value of the total welfare the most.

The instrument ranking obtained in this paper runs strongly counter to most of the current literature on the relation between environmental policy and technological adoption, showing that there is no unique ranking and which instrument induces an earlier adoption and a greater welfare depends on several conditions, as for example, the market structure. In fact, most existing studies consider than the only flow of benefits of adoption corresponds to the savings in the total abatement cost. Once the technology is available, market based instruments would induce firms to reoptimize their level of abatement, so the savings using these instruments would the higher. Then, emission taxes should be preferred over tradable permit systems while emission standards should be at the bottom of the list. As the output of the firms is not considered, the instrument producing the early sequence of adoption would produce also the greatest welfare. However, under rivalry on the final product market, the firms´s incentives to produce are modified and a new flow of benefits of adoption must be considered. The profits obtained because of the increase in the output speed up the sequence of adoption under an emission standard and at the same time the total welfare induced by each instrument is modified.

"Environmental Policy and the Timing of Technological Adoption in Santiago, Chile: The Natural Gas Case "

Technological change is maybe the main tool to face environmental problems in the long run. For that reason, the relation between technological change and environmental policy has received special attention because it is well known that environmental policy affects the incentives for firms to produce or to adopt a new technology, and through this mechanism, it affects the social cost of different policies. If a particular instrument can induce more R&D activities or an earlier adoption of cleaner technologies, it would be preferred for policy makers. However, the way an instrument modifies incentives is not clear and it could depend on several conditions.

Over the last decades, special attention has been placed to these topics. Two areas of research have been explored: - one focused to understand the potential of different policies to generate innovation and another concentrated in understanding how policies, that increase the economic incentives to reduce pollution affect the rate at which the existing technologies are adopted.

Most of the work developed in both areas has been theoretical rather than empirical. However, the evidence generate for both approaches has been consistent with the finding that market-based instruments are likely to have significantly greater positive impacts than command and control policies to induce innovation or diffusion of desirable environmentally friendly technologies. All the accumulated evidence refers to the United States´s case and there isn´t an equivalent study to evaluate the performance of such policies in a developing country due the lack of reliable data.

The aim of this study is to test the theoretical prediction that policy instruments differ in their effects over technological adoption in an emerging country, considering the case of the stationary sources of pollution in Santiago, Chile.

Stationary sources have faced since 1990 several regulations encouraging the particulate matter emissions´s reductions. In general terms, it can be said that the Chilean environmental regulation classified stationary sources into large and non large boilers and applied a different policy mix to each group. Large boilers were included in a tradable permit program while non large boilers were subject to a standard that restricted the concentration of the emissions discharged through their ducts or stacks. At the same time, both groups were included in a contingencies program that forced to the dirtiest sources to shutdown during bad air quality episodes.

The common response to the regulation´s requirements was to switch to natural gas, a cleaner fuel that began to be imported from Argentina in 1997. In a couple of year, more than a half of the stationary sources were burning this fuel, raising the question about the drivers of such a fast adoption process.

The heart of the paper is an empirical analysis of the switching to natural gas The adoption of such a fuel granted sources with several flows of benefits. It decreased the cost of energy, since the price of this fuel was lower than the price of the rest of the cleaner fuels. It decreased the expected cost of being closed since the switching allowed sources to leave the contingencies program. It reduced also the quantity of emissions rights required for large boilers.

To disentangle the role of such flows of benefits on the adoption decision and its timing, a hazard model is estimated, using a panel data of more than 5.000 stationary sources.

The empirical analysis suggests that the decreased in the cost of the energy was the main catalyst of the switching process, showing that sources were more sensitive to changes in the cost of an input than to the environmental regulation. In fact, the effects of the contingencies system, that seemed strongly correlated with the adoption process, are scarce while there is not effect of the tradable permit program inducing adoption.

Chilean environmental policies did not increase the economic incentives to switch to a fuel that reduced the costs of fulfillment, which arises questions about the design aspects of such policies. In the case of the contingencies system, differences in the monitoring and enforcement efforts across sources could be driving the results. On the other hand, the poor performance of the Santiago´s tradable permit program appears to be explained by a combination of mistakes in its design and implementation.

"Transactions in The Santiago Emission Market: ¿Why did sources lost their emissions rights?"

In 1997 an emission compensation program was launched in Santiago to control particulate matter. Due to their easy identification and their relative importance, the program focused in large boilers, which at the time of implementation were the largest emitters. All large boilers existing in 1992 were granted emission rights. They could use their permits or sell them to other existing sources or to those sources that entered the market after 1992 which did not receive emission rights. If they decided not to trade their rights, they must remain operative to keep them. If not, a short period of time is allowed to exchange the permits before they become void. So far, almost 20% of the initial mass of emission rights granted became void due to this restriction. ¿Why did sources did not trade their permits before they became void? . In this essay it is argued that design and implementation issues are responsible for the absence of exchange behind the loss of emission rights.

Three hypothesis are analyzed. The first is that most sources relied on autarkic compliance, and there were no incentives to trade since the implicit permit price was zero. The second is that the existence of substantial transaction costs discouraged sources to trade permits, and the third is that the misunderstanding of the system led sources not to trade before the legal deadline. Data on transactions does not allow to discard any hypothesis. In fact, since the beginning of the system the quantity of emission rights has exceeded the requirements, producing a very significant excess of supply. At the same time, the extensive period of time required to get a transaction approved by the regulator seems to have reduced the trading probability. Small boilers, which faced the highest costs of acquiring information about the working of the tradable permit program appears to be the group that lost more emission permits.

Chapter 3

Environmental Policy and The Diffusion of a New Technology

3.1 Introduction

It has been well documented in the literature [See Geroski (2000), Jaffre et al. (2002)] that one of the central features of technological diffusion is the apparently slow speed at which firms adopt new technologies. As a matter of fact, the time path of adoption typically follows and S-curve, where a period of relatively rapid adoption follows an initial period of slow taking off and precedes a late period of slow approach to satiation.

If a new technology is a significant improvement over existing technologies, it is important to ask why some firms adopt earlier than others and which policies may help to accelerate this process. This is specially true in the environmental field, where much of the adverse impacts of many technologies currently in use, could be reduced bringing into use more environmental friendly technologies.

Policymakers have usually a wide range of policy options to affect firms´s behavior. Considering that a faster diffusion rate of cleaner technologies could reduce the social cost of programs that try to improve the environmental quality, it is worth asking how environmental policy instruments than implicitly or explicitly increase the economic incentives to reduce emissions, affect the diffusion rate of these technologies.

This question has been analyzed partially by many researchers, leading to the generation of different rankings that tend to support the use of market instruments over command and control policies, but with little agreement about the supremacy of a market tradable system over an emissions tax. Most existing studies explore the adoption under a static framework and hence, have been unable to study the dynamics aspects behind adoption that can give account of the diffusion´s graduality, missing the impacts that one firm´s decision could have over its rivals. This paper is an attempt to include such elements and analyze how they can alter existing instrument rankings. More specifically, the effects that the strategic interaction on the final product market has over the profitability of adoption and the effects of learning about the scope of the new technology are explored.

The main findings are that under such a scenery, the rate of adoption is strongly depended on market conditions and that if well a command and control instrument does not produce the fastest sequence of adoption, the total welfare associated with its pattern of adoption can be the highest.

3.2 Literature Review

As it was pointed out by Geroski(2000), it is hard to understand why decisions sometimes take a long time to be made, specially when important benefits are involved. The diffusion of a new technology could be a good example of this problem since it seems to take an amazingly long period of time for new technologies to be adopted by those who most likely seem to benefit from their use. Actually, it is a stylized fact that the time path of adoption usually follow an S-curve, where a slow take up leads a period of relatively rapid adoption followed by a period of slow approach to satiation.

If a new technology improves the firms´s performance, it is important to ask why some firms shift over time more slowly than others. Possibly the simplest way to think about it is to suppose that firms differ in some characteristic that affect the profitability of adopting the new technology x_i, and that firms will adopt it if x_i exceeds some cost threshold x^*. If we assume that the heterogeneity is distributed across firms according to some function $f(x)$,the adoption timing follows a S shaped curve since those firms with levels of x_i larger than x^* will adopt immediately. If the cost threshold x^* follows over time, the diffusion rate will gradually rise as we move to the right side of the distribution and then will fall as we move to the left side, generating the usual adoption curve. Therefore, it can be said that the diffusion of a capital embodied process innovation results from a pattern of decreasing profitability and decreasing adoption costs for sequential adoptions.

There are many theoretical models of adoption timing than can be classified according to the exogenous factors driving diffusion.[1] Some elements that have been analyzed are firm size, uncertainty regarding the arrival and the value of the new technology, learning and search costs and switching costs. All of them are likely to have a major impact on diffusion since as time passes (and information and usage increases) they could enable firms that have not yet adopted to reassess their decision. Another important driver could be the strategic interaction in the product market since under rivalry, a firm´s pre-adoption and post-adoption profits may depend on the number of firms that have previously adopted. A firm´s incentive to adopt a new technology at a certain point in time may crucially depend on the rival firms, thus speeding up the first adoption or rising a late-mover advantage, that would slow down adoption.

[1] Hoppe (2002) presents a good review of both the theoretical and empirical developments about the timing of new technology adoption.

However, the focus of this paper is not the timing of adoption per se, but rather how this timing can be modified through the use of different environmental policy instruments and the welfare produced by each sequence of adoption. These are very important policy questions since speeding up the adoption of more efficient technologies could reduce the social cost of programs that try to improve the environmental quality in the short run. Besides, technical progress is perhaps the main tool to solve environmental problems in the long run. If a particular instrument could induce a faster adoption of environmentally friendly technologies and the greatest social welfare, it should be preferred for policymakers.

Previous findings about the relationship between technological adoption and environmental policy include the works of Downing and Prince (1986), Milliman and Prince (1989), Jung, Krutilla and Boyd (1996), Keohane (1999), Montero(2002) and Van Soest (2005). Most of them have used a static setting to argue that the adoption incentive is greater under market-based instruments than under direct regulations, using as the measure of incentives the aggregate savings to the industry as a whole from adopting the new technology.

Downing and Prince (1986), for example, considering the case of a single polluter, argue that taxes and tradable permits are essentially equivalent. On the other hand, Milliman and Prince(1989) [henceforth MP] analyze the case of multiple homogeneous firms, finding that auctioned permits provide the largest incentives, followed by emissions taxes, subsidies, freely allocated permits and direct controls, while Jung, Krutilla and Boyd (1996) [henceforth JKG] replicate the previous ranking, but considering heterogeneous firms.

Keohane (1999) points out the limited usefulness of the measure of incentives used by MP and JKG. In fact, comparing the aggregate cost savings among different instruments is no appropriate to analyze how those instruments influence the diffusion among firms. Such a measure does not allow us to distinguish the gains that are attributable to a firm´s adoption decision from those gains that the firm would have received anyway. Using a more meaningful measure of "firm-level incentives", Keohane (1999) finds that there are no differences between auctioned or freely allocated tradable permit systems and that permit systems provide lower adoption incentives than taxes.

Montero (2002) adds a different dimension to the previous analysis, comparing instruments in a static framework with strategic interaction. He models emissions as a production input and evaluates the adoption profits in the presence of oligopoly final markets. His main result is that due to the existence of strategic and direct incentives, there is no unique ranking of instruments and that standards can offer even greater incentives than market tradable permits depending on market conditions.

Finally, Van Soets (2005) analyzes the impact of the choice of policy instruments on the timing of the investment of energy savings technologies. He assumes that new generations of energy savings technologies will become available at unknown future dates, and defines the "adoption lag" as the number of periods that elapses until a firm purchases a new technology. He analyzes whether taxes or a non-tradable quota system are more conducive to early adoption, concluding that for low levels of environmental stringency (measured in terms of either higher taxes or smaller equivalent quotas) the adoption lag under a tax regime is larger than under quotas, while the reverse holds for high levels of environmental stringency.

In the Van Soests´s model, the driver of diffusion is the uncertainty regarding future technological options. In this paper, the effects that strategic interaction in the final product market and in the new technology purchase market have over the diffusion of a new technology are explored .

The paper is organized as follows. Next section introduces the model used and the optimal timing of adoption obtained from it. The third section analyzes how the optimal date of adoption changes depending on the selected instruments. In the fourth section, timings of adoption for each instrument are simulated under different assumptions, and the consumer surplus and the total welfare paths associated with each timing of adoption are evaluated. The fifth section concludes.

3.3 The Model

Reinganum (1981) analyzes the impact of market structure upon the rate of adoption of a new technology. She finds that due to strategic behavior, the value of adopting a cost-reducing innovation declines with the number of firms that have already adopted it, producing a sequence of adoption that is "diffused" into the industry over time. In this paper, a very similar version of her model is used to explore how different environmental policies affect this sequence of adoption.

Suppose that a stationary industry of n firms is producing an homogeneous good whose linear inverse demand function is given by:

$$\begin{aligned} P(q_1, q_2, ...q_n) &= a - b\sum_{i=1}^{n} q_i \\ a, b &> 0 \end{aligned} \tag{3.1}$$

Where q_i denotes the level of production of firm i.

Firms do not have any production cost and in the absence of any environmental regulation, each unit of output generates a unit of emission e ($\partial e_i/\partial q_i = 1$).

The goal of the environmental authority is to reduce the level of global emissions up to $\bar{E}$. To achieve that, he is evaluating the use of the following policy instruments:

- an emission standard that sets up a maximum emission level equal to $\bar{e}$ for each firm.
- an emission tax, under which each firm must pay g dollars for each unit emitted.
- a tradable permit system where $\bar{E}$ permits are auctioned off.

To meet the environmental regulation, each firm in the industry has installed previously an abatement technology. The total abatement cost for each source can be described as $c_i r_i^2$, where r_i is the quantity of emissions that firm i abates, or:

$$r_i = q_i - e_i \tag{3.2}$$

Hence, current abatement costs are heterogeneous. It is assumed that firms can be ordered according to their abatement costs, indexing them, without loss of generality, from the firm with the highest cost to the firm with the lowest cost, so $c_1 > c_2 > ... > c_i > .... > c_n$.

They may differ in their abatement cost because at the date each firm entered to the industry there was a different set of abatement technologies available. However, a new technology becomes available to all firms at a cost K, that reflects the purchase price plus any adjustment costs required to bring it into use. This new technology allows firms to reduce emissions to a lower cost c, where $c_1 > c_2 > ... > c_i > .... > c_n > c$. No further technical advance is anticipated.[2]

It is assumed that as the number of firms that have adopted the new technology increases, also increases the number of suppliers of it, which implies that the present value of the investment K, decreases with the number of firms that have already adopted at a rate θ_i, where θ_i exhibits the usual properties $\theta_i' > 0$ and $\theta_i' < 0$[3].

So, given the availability of the new technology, each firm must decide whether to adopt it and the date of adoption.

Let τ_i be the date of adoption of firm i. $\rho(\tau_i)$[4] represents the present value of the

[2] If firms anticipate that a better tecnology would arrive at an uncertain date, they must consider suspending the current adoption process in light of the expectations of future technological improvements. The suspension of the current process provides the firm with an option to purchase the future technology when it becomes available. The value of this option must be equal to the expected net present value of the future technology. So, the profitability threshold required in order to adopt the current best technology increases, delaying the entire timing of adoption. However, I do not expect the new threshold to depend on the choice of the regulatory policy, so I exclude this possibilty to simplify the analysis.

[3] This means that the purchase price and the adjustements costs of the technology decreases with each new sequential adoption at a decreasing rate.

[4] Reinganum (1981) established the following conditions on $\rho(\tau_i)$ to have a sequential pattern of adoption.

Condition 1 $\rho'(0) \leq \pi_{oi}(0, n) - \pi_{1i}(1, n)$

Condition 2 $lim_{t\to\infty} \rho'(\tau) > 0$

Condition 3 $\rho'(\tau) > re^{-rt}[\pi_{1i}(1, n) - \pi_{0i}(0, n)]$ *for all* $\tau \in [0, \infty)$

The first condition establishes that inmediate adoption is too costly, except maybe for the first adopter.

The second condition establishes that the cost saving from spreading out the initial investment cannot continue indefinitely.

The third condition is that $\rho(\tau_i)$ increases at a increasing rate as the length of the τ decreases, which means that the objetive function of each firm is locally strictly concave in the choice variable τ.

investment required to obtain the new technology

$$\rho(\tau_i) = Ke^{-(\delta+\theta_i)\tau_i} \tag{3.3}$$

Where δ represents the intertemporal discount rate.

Let $\pi_{oi}(m,n)$ be the rate of Cournot Nash profit flow to firm i when m of n firms have adopted the new technology and firm i belongs to the fraction that has not adopted yet. Let $\pi_{1i}(m,n)$ be the rate of Cournot Nash profit flow to firm i when m of n firms have adopted and firm i belongs to the fraction that has already adopted . It is assumed that $\pi_{oi}(m,n)$ and $\pi_{1i}(m,n)$ are known with certainty by each firm as also the marginal cost of the new technology.[5]

The decreasing ordering in the abatement costs allows to predict the sequence of adoption $\tau_1 \leq \tau_2 \leq ......\tau_{i-1} \leq \tau_i \leq \tau_{i+1} \leq ..... \leq \tau_n$ due to the fact that for the same initial investment K, firm 1 benefits the most from technological adoption.

Given the ordering, the present value of firm i´s profits net of the adoption costs when it adopts the new technology at a date τ_i can be characterized as $V^i(\tau_1,.,\tau_i,.\tau_n)$:

$$V^i(\tau_1,.,\tau_i,.\tau_n) = \sum_{m=0}^{i-1} \int_{\tau_m}^{\tau_{m+1}} \pi_{0i}(m,n)e^{-\delta t}dt + \sum_{m=i}^{n} \int_{\tau_m}^{\tau_{m+1}} \pi_{1i}(m,n)e^{-\delta t}dt - \rho(\tau_i) \tag{3.4}$$

The optimal date of adoption for each firm can be found maximizing V^i via the choice of τ_i from the interval $[\tau_{i-1}, \tau_{i+1}]$.

$$\frac{\partial V^i}{\partial \tau_i} = [\pi_{0i}(i-1,n) - \pi_{1i}(i,n)]\, e^{-\delta\tau_i^*} - \rho\'(\tau_i^*) = 0 \tag{3.5}$$

Replacing 3.3 into 3.5, we find that

[5] The certainty in the extent of the cost reduction, it is an assumption that can be easily modified. We can assume that c is a random variable drawn from the interval $m = [\underline{c}, \overline{c}]$, according to the uniform distribution $F(.)$.If $m_i = m_j$ and $F_i(.) = F_j(.)$ for all i, j, we shall say that the uncertainty is innovation specific. In this case, the predicted pattern of adoption does not change, but as a firm´s action reveals information about the profitability of the investment, the other firms wait to see what the other firms will do.

The timing of adoption will be delayed since firms wait to see the value of the realization c_{i-1} before taking a decision. In fact, the optimal date of adoption for each firms become:

$$\tau_i^* = \frac{1}{\theta_i} \ln\left(\frac{(\delta+\theta_i)K}{\pi_{1i}(i,n) - \pi_{0i}(i-1,n)}\right) * \frac{1}{\prod_{j=0}^{j=i} F_j(.)}$$

So, like in the case of further technical advance, the profitability threshold required in order to adopt the technology increases, but again I do not expect the new threshold to depend on the choice of the regulatory policy, so I exclude it to keep the analysis as simple as possible.

$$\tau_i^* = \frac{1}{\theta_i} \ln \left(\frac{(\delta + \theta_i)K}{\pi_{1i}(i,n) - \pi_{0i}(i-1,n)} \right)^6 \tag{3.6}$$

The intuition behind this result is clear. Firm i will adopt the new technology when the costs of delaying adoption equals the benefits. The costs of delaying adoption correspond to the difference in the profit flows due to the lower abatement cost, while the benefits of postponing adoption are equal to the opportunity cost of saving the initial investment. When both elements are equal, firm i adopts.

Each environmental policy instrument produces a different value for the change in profits, changing the optimal date of adoption within the interval $[\tau_{i-1}, \tau_{i+1}]$. At the same time, the instrument that induces the biggest difference for the early adopters will encourage the earliest timing of adoption since the cost of adoption decreases faster when a considerable fraction of firms have adopted. So an early adoption of the former make more profitable an early adoption of the rest.

Next, the value of the difference in profits under each environmental policy instrument is analyzed.

The Date of Adoption Under An Uniform Emission Standard: To reduce emissions the policymaker can put a cap to the quantity of emissions allowed. The standard lets each firm in the industry to produce a maximum of $\overline{e}$ emissions, where $\overline{e} * n = \bar{E}$

To calculate the adoption profits for firm i , it is necessary to determine the Nash equilibrium in prices and quantities, either when it belongs to the fraction of firms that has not yet adopted and when it belongs to the fraction that has already adopted.

Firms producing with the new technology must choose their level of production with the objective of maximizing their profits subject to the maximum level of pollution established by the standard. This means that any of the $(i-1)$ firms that have already adopted must solve the following maximization problem:

$$\begin{aligned} Max_{q_j} \pi_j &= P(q_1, q_2, ...q_n) q_j - c(q_j - \overline{e})^2 \\ & \quad s.a \\ q_j &\leq \overline{e} \\ j &= 1, 2, ..., (i-1) \end{aligned} \tag{3.7}$$

Where the abatement cost correspond to the cost of the new technology.

At the same time, the $(N-i+1)$ firms using old technologies must solve a similar problem, but facing a higher abatement cost:

[6] As it was shown for Reinganum(1982), the sequence of adoption $\tau_1 < \tau_2 < .... < \tau_n$ is a Subgame Perfect Equilibrium.

$$\begin{aligned} Max_{q_k}\pi_k &= P(q_1,q_2,.....,q_n)q_k - c_k(q_k-\overline{e})^2 \\ & s.a \\ q_k &\leq \overline{e} \\ k &= i,(i+1),(i+2)...,n. \end{aligned} \tag{3.8}$$

As it can be seen, this is an usual Cournot-Nash game with cost heterogeneity across firms, where the level production of each firm depends inversely of its own cost and positively of its rivals´s costs.

Two conditions are being satisfied in equilibrium:

1)At the optimal level of production, each firm faces a benefit per unit produced equal to the marginal abatement cost. This means that those firms that have adopted, increase their level of production after the adoption. Thus, technological adoption modifies the adopters´s incentives to produce.

2)The optimal level of abatement equals the difference between the optimal level of production and the emission standard. As the optimal level of production increases after adoption and the standard remains the same, the optimal level of abatement of those firms adopting the new technology increases. At the same time, the total cost of the initial abatement is reduced.

This means that in this case, the benefits of technological adoption come from two sources: - a flow of profits due to the additional production and - a flow of savings since thanks to the new technology firms abate at a lower cost.

The Date of Adoption Under An Uniform Emission Tax: Each firm maximizes profits looking for the optimal level of production and the mix abatement-tax payment. If the environmental authority has decided to charge a fee equal to g per unit of emission, early adopters maximize the following function:

$$\begin{aligned} Max_{ej,q_j}\pi_j &= P(q_1,q_2,.....,q_n)q_j - c(q_j-e_j)^2 - ge_j \\ j &= 1,2...,(i-1). \end{aligned} \tag{3.9}$$

Where the abatement cost corresponds to the cost of the new technology.

Firms that have not already adopted solve a similar problem, but facing a higher abatement cost:

$$\begin{aligned} Max_{e_k,q_k}\pi_k &= P(q_1,q_2,.....,q_n)q_k - c(q_k-e_k)^2 - ge_k \\ k &= i,(i+1),(i+2)...,n \end{aligned} \tag{3.10}$$

From the first order conditions for e_i, and e_j it is possible to find that the level of abatement of adopters r_j is higher than the level of abatement of non adopters r_k:

$$\begin{aligned} 2cr_j &= g \\ j &= 1,2,...,(i-1) \end{aligned} \tag{3.11}$$

$$\begin{aligned} 2c_K r_k &= g \\ k &= i,(i+1),(i+2),...,n \end{aligned} \tag{3.12}$$

Additionally, as all firms face at the margin a per unit cost equal to the tax, the level of production of adopters and non adopters is the same and equal to q_g^*.

$$q_g^* = \frac{(a-g)}{b(n+1)} \tag{3.13}$$

So again, two conditions are being satisfied in equilibrium:

1) At the optimal level of production, each firm faces a cost per unit produced equal to the emission tax. Since it is assumed that the tax does not change over time, the optimal level of production does not change with adoption. Thus, technological adoption does not affect the firm´s incentives to produce.

2)At the optimal level of abatement, each firm faces a marginal abatement cost equal to the emission tax. Since firms that have already adopted face a lower marginal abatement cost, they will prefer to reduce further emissions rather than paying the tax. Hence, technological adoption increases the optimal level of abatement and consequently, the total cost of the mix abatement-tax payment diminishes.

This means that in the emission tax case, the benefits of technological adoption come from the savings because firms reoptimize the mix abatement-tax payment.

The Date of Adoption Under A Tradable Permit System: Under an auctioned tradable permit system, each firm must decide the level of production and the mix abatement-emission permits that maximizes its profits. Let ε_j be the quantity of emissions permits in property of firm j and s to be the equilibrium price of an emission permit.

So, early adopters must solve:

$$\begin{aligned} Max_{q_{j,\varepsilon j}} \pi_j &= P(q_1, q_2, ...q_n)q_j - c_j(q_j - \varepsilon_j)^2 - s\varepsilon_j \\ j &= 1,2..(i-1) \end{aligned} \tag{3.14}$$

Where the abatement cost corresponds to the cost of the new technology.

While those firms using older technologies must solve:

$$\begin{aligned} Max_{q_{k,}\varepsilon_k}\pi_k &= P(q_1,q_2,.....q_n)q_k - c(q_k-\varepsilon_k)^2 - s\varepsilon_k \\ k &= i,(i+1),(i+2),....,n \end{aligned} \tag{3.15}$$

From the first order conditions for ε_i, and ε_j it is possible to find that the level of abatement of adopters r_j is higher than the level of abatement of non adopters r_k.

$$\begin{aligned} 2cr_j &= s \\ j &= 1,2,...,(i-1) \end{aligned} \tag{3.16}$$

$$\begin{aligned} 2c_K r_k &= s \\ k &= i,(i+1),(i+2)...n \end{aligned} \tag{3.17}$$

Additionally, as all firms face at the margin a per unit cost equal to the emission permit price, the level of production of adopters and non adopters is the same and equal to q_s^*.

$$q_s^* = \frac{(a-s)}{b(n+1)} \tag{3.18}$$

Again, two conditions are being satisfied in equilibrium.

1) At the optimal level of production, each firm faces a cost per unit produced equal to the emission permit price. Assuming that the emission permit price does not change over time, it can be said that the optimal level of production does not change because of adoption. Thus, technological adoption does not affect the firm´s incentives to produce.

2)At the optimal level of abatement, each firm faces a marginal abatement cost equal to the emission permit price. Assuming that the emission price does not change over time, firms will prefer to reduce more emissions instead of buying permits. So, technological adoption increases the optimal level of abatement and consequently, the total cost of the mix abatement- emission permits diminishes.

As in the emission tax case, the benefits of technological adoption under a tradable permit system would come just from the savings in the total abatement cost. In fact, if the emission tax would be equal to the tradable permit price, the aggregate production and abatement would be equivalent under both instruments as would also be the timing of adoption of firm i within the interval $[\tau_{i-1}, \tau_{i+1}]$. Hence, both instruments would generate the same overall sequence.

However, the price of the emission permit will change after each technological upgrade in such a way that is going to affect the adoption benefits and the adoption rate.

It is easy to show that the emission permit price is a function of the number of firms that have already adopted. Thus, in this model, if i of the n firms are using the new technology, the equilibrium price of the emission permit will be equal to[7]:

$$s^*(i) = \frac{\frac{n*a}{b(n+1)} - \bar{E}}{i * \frac{1}{2c} + \sum_{j=i+1}^{n} \frac{1}{2c_j} + \frac{n}{b(n+1)}} \tag{3.19}$$

Clearly, the price decreases after each sequential adoption $[\frac{\partial s^*(i)}{\partial i} < 0]$ which leads to firms to reoptimize the level of abatement and production.

Every time a firm adopts, the total cost of the mix abatement- emission permits is reduced for all firms in the industry, including those that have not yet adopted because all firms can buy emission permits to a lower price. Therefore, this price endogeneity would make more profitable waiting until a larger fraction of firms has adopted instead of adopt quickly. If each firm foresees the price behavior, the overall sequence of adoption could be delayed.

The price endogeneity affects also the incentives to produce since the implicit cost of production, given by the price of the permit, decreases. However, unlike the standard case, the reduction in this cost is made extensive to all firms, including those that have not yet adopted. Due to the rivalry in the final product market, adopters will increase their output in a lower fraction with regards to an emission standard. Then, we should expect that the flow of adoption´s benefits coming from an increase in the output will be smaller in this case.

Regarding the optimal level of abatement, the price endogeneity causes also a lower increase in the level of abatement with regards to an emission tax, given that the option of buying permits is less expensive.

[7] In fact, from 3.16 and 3.17 it is posible to derivate the optimal level of emissions for adopters and non adopters, where i belongs to the fraction of firms using the new technology:

$$\begin{aligned} \varepsilon_j &= q_s^* - \frac{s}{2c} \\ j &= 1, 2, ...i \end{aligned}$$

$$\begin{aligned} \varepsilon_k &= q_s^* - \frac{s}{2c_k} \\ k &= i, (i+1), (i+2) \end{aligned}$$

Adding the required emissions and making them equal to the emissions supply $\overline{E}$, I find the price s that clear the market

$$n * \left[\frac{a-s}{b(n+1)}\right] - i\frac{s}{2c} - \sum_{k=i+1}^{n} \frac{s}{2c_k} = \overline{E}$$

In sum, under an auctioned off tradable permit system, the benefits of technological adoption come from both an increase in the level of production and an increase in the level of abatement. But the price endogeneity reduces the profitability of additional reductions, so the flow of adoption profits coming from savings in the total abatement cost will be smaller than in the tax case. At the same time, as adoption will make profitable to increase the output of all firms, the flow of adoption profits coming from this source will be smaller than in the case of the standard.

Figure N° 1 shows the incentives comparison between an emission tax and an emission standard for firm i. Firm i maximizes its profits setting its level of production where the marginal benefit equals the marginal cost. Because of the market structure, the production benefit is a decreasing function of its own level of output while is parametric on its rivals´s output. The only cost of production corresponds to the abatement cost.

Due to the linear relation between production and emissions, we can measure both of them along the horizontal axis, while the difference between the optimal output and the optimal emissions correspond to the abatement r.

Let´s assume that the environmental authority is looking for a level of emissions consistent with $\overline{q}$ units of output. The existence of the current technology allows to the firm i to reduce the adverse impacts of such a restriction over its profits. Under the tax, instead of paying a fee equal to g per each unit produced, firm i will abate r_0^{tax} units, paying just for $[\overline{q} - r_0^{tax}]$ emissions. Under the standard, firm i will increase its level of production to q_0^N,abating all the emissions that exceed $\overline{q}$,which means $(q_0^N - \overline{q})$ units.

So, given the marginal cost of the current technology MC_0, the tax is expected to induce a level of abatement equal to r_0^{tax} while $(q_0^N - \overline{q})$ units will be abated under the standard.

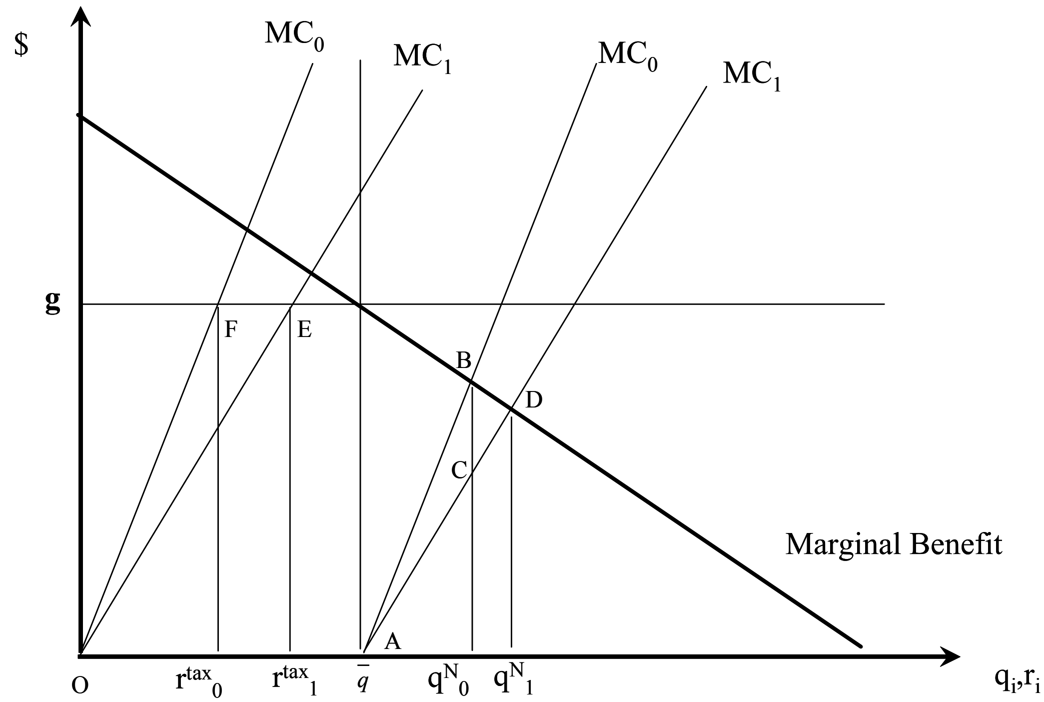

Figure N° 1: A Tax Versus A Standard

After adoption, the marginal cost is reduced to MC_1 and the level of production increases under the standard to q_1^N and remains unchanged under the tax. However, in both cases, abatement increases. If a tax would be used $(r_1^{tax} - r_0^{tax})$ additional emissions would be abated while the standard would encourage an additional abatement equal to $(q_1^N - q_0^N)$.

Therefore, the adoption profits under the tax would be equal to the area OEF, that is equal to the savings due to the lower total cost of the mix abatement-tax payment. In the meantime, the standard generates adoption profits equal to the area $\overline{q}BD$.This includes the savings due to the lower abatement cost of the initial abatement (ABC) plus the net benefits of the additional production (BCD).

The tax is expected to induce an earlier adoption since is fixed at a higher marginal value. Thus, the marginal value of the additional abatement under the tax it is larger than the marginal value of the additional production induced by the standard. Then, the benefits of the extra production should not compensate the lower savings in the total abatement cost.

Figure N° 2 shows the incentives comparison between an emission tax and a tradable permit system for firm i.

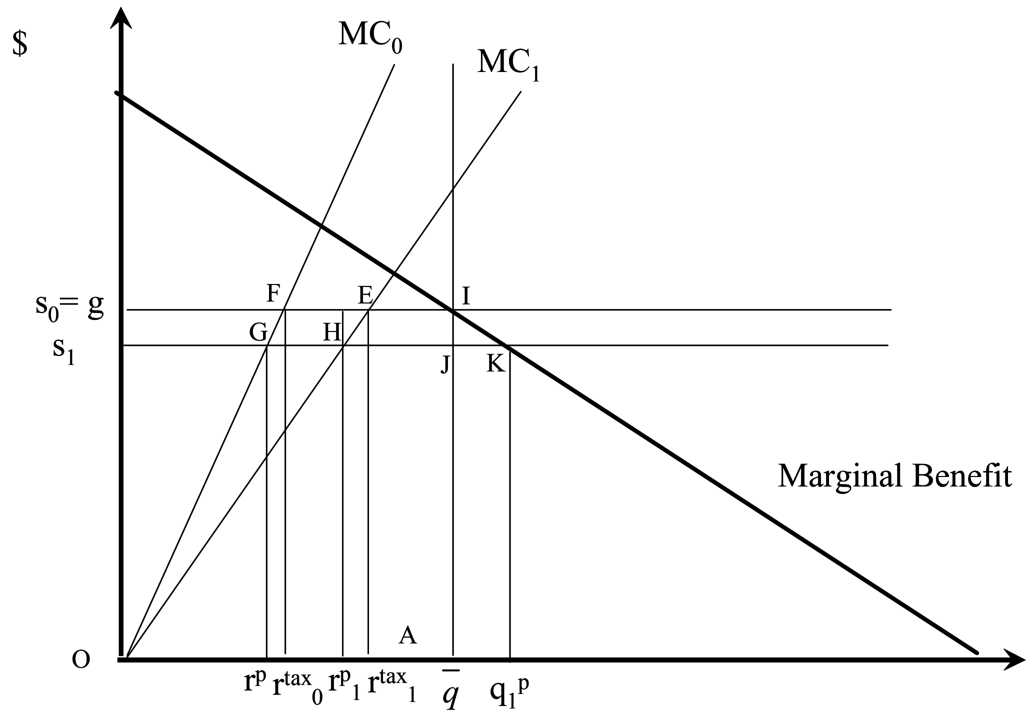

Figure 2: A Tax Versus A Tradable Permit System

Again, the environmental regulation induces previously $\overline{q}$ units of output, while s_0 correspond to the initial price of an emission permit and it is equal to the tax g.

If firm i would be regulated by a tradable permit system, after the adoption, the emission permit price would decrease to s_1, encouraging firm i to increase its output to $q^p_{1.}$ while if an emission tax would be used, the output would remain unchanged. Regarding the mix abatement-emission permits, firm i would abate r^p_1 units while $[q^p_1 - r^p_1]$ emission permits would be acquired.

Then, there are two sources of adoption benefits under a tradable permit system: - the area IJK that represents the net profits because of the additional production and - the area OGH that represents the savings due to the lower cost of the mix abatement-emission permits. Clearly, the savings are smaller than area OFE. This happens because of the price endogeneity. When firm i adopts, the price of the permit falls from s_0 to s_1, making the option of buying permits more profitable. Thus, the mix abatement-emission rights tends to the use of more permits, even although the lower marginal abatement cost $[r^p_1 < r^{tax}_1]$.As in the previous comparison, the tax is expected to induce an earlier adoption than the tradable permit system since is fixed at a higher marginal value than the marginal value of the additional production induced by the tradable permit system. Then, the benefits of the extra production should not compensate the lower savings in the total abatement cost.

Finally, Figure N° 3 shows the incentive comparison between an emission standard and a tradable permit system for firm i. This is perhaps the most difficult case because the flow of profits coming from the savings in the total abatement cost is expected to be higher under a tradable permit system (area OGH versus ABC). At the same time, the flow of profits coming from an increase in the level of production is expected to be higher under the emission standard (area BCD versus IJK).

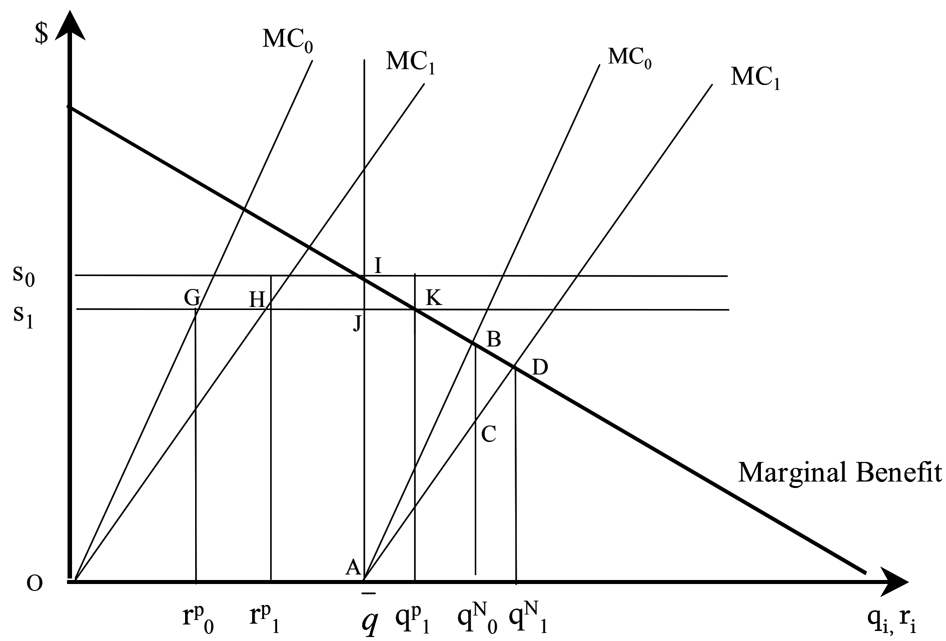

Figure 3: A Standard Versus A Tradable Permit System

Next section presents some numerical simulations to give account of the magnitude of such effects.

3.4 Simulations

In this section, the pattern of adoption induced by each policy instrument is analyzed. For that purpose, a numerical simulation of the effects mentioned previously is undertaken. It is established a set of central values for the parameters and examine a wide range of variations around this. It was chosen $N = 20$, $a = 800$ and $b = 1.0$, which means that in the absence of environmental regulation, there would be approximately 762 units of global emissions. The environmental target is to reduce such emissions to 300 units.

It is assumed that the marginal cost of the best currently technology available follows an uniform distribution between 10 and 30. The marginal cost of the upgraded technology is equal to 7, so all firms potentially obtain benefits from adopting it. The rate of discount is equal to 10% while the rate of learning follows an uniform distribution between 15% and 0%.The investment required to bring the technology in use is equal to $US\$30.000$.

Representative simulations results are shown in Figure N° 4 and Figure N° 5. In both figures, the optimal date of adoption for each firm is measured along the horizontal axis, and the number of firms that have already adopted on the vertical axis.

In this numerical example it is concluded that the emission tax induces the fastest sequence of adoption, followed by the emission standard and the tradable permit system. In Figure N° 1 we can see that if an emission tax would be used, the entire industry would adopt within a period of 20 years. Instead, if an emission standard would be used, the entire sequence would last more than 39 years while under a tradable permit system this period would be extended to 44 years.

Figure N° 5 displays the pattern of adoption for a higher value of the inverse of the price elasticity, $b = 1.5$. It can be seen that the previous result remains, but adoption is slower, no matter the policy instrument. In fact, it takes almost the the double of time to each instrument to encourage the adoption of all firms. The reason is that when demand is more inelastic, the emissions that firms would produce in the absence of environmental regulation are lower [508 units instead of 762] Then, the stringency of the policies is lower and also the benefits of adoption, delaying the sequence of adoption.

The timing of adoption also depends strongly on the cost heterogeneity among firms and the marginal cost of the upgraded technology. If the reduction in the marginal abatement cost due to adoption is substantial, we should see an earlier timing. The same result would be obtained if sources are not very heterogeneous, since in this case the flow of adoption profits are quite similar among sources, likewise the timing.

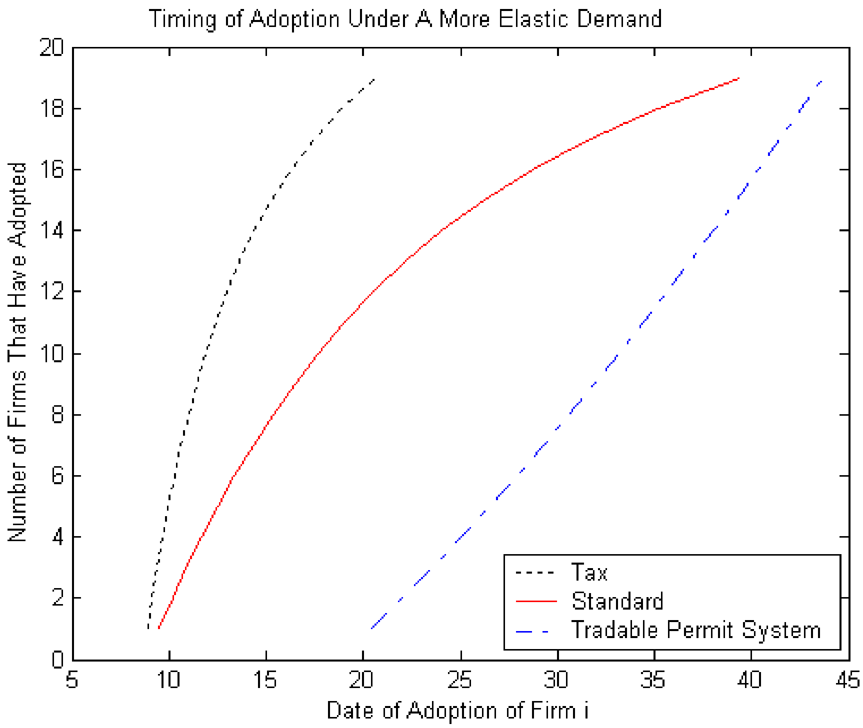

Figure N° 4: The Timing of Adoption Under An Elastic Demand

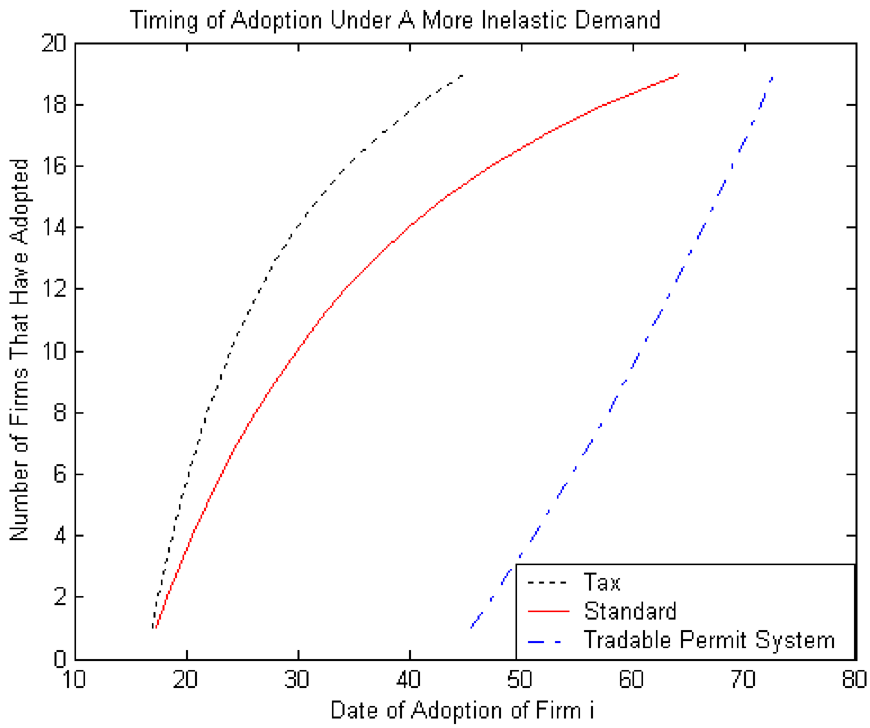

Figure N° 5:Timing of Adoption Under An Inelastic Demand

Regarding the differences on the timing of adoption, the numerical analysis suggest that the effect of the lower total abatement cost dominates over the effect of the extra production.

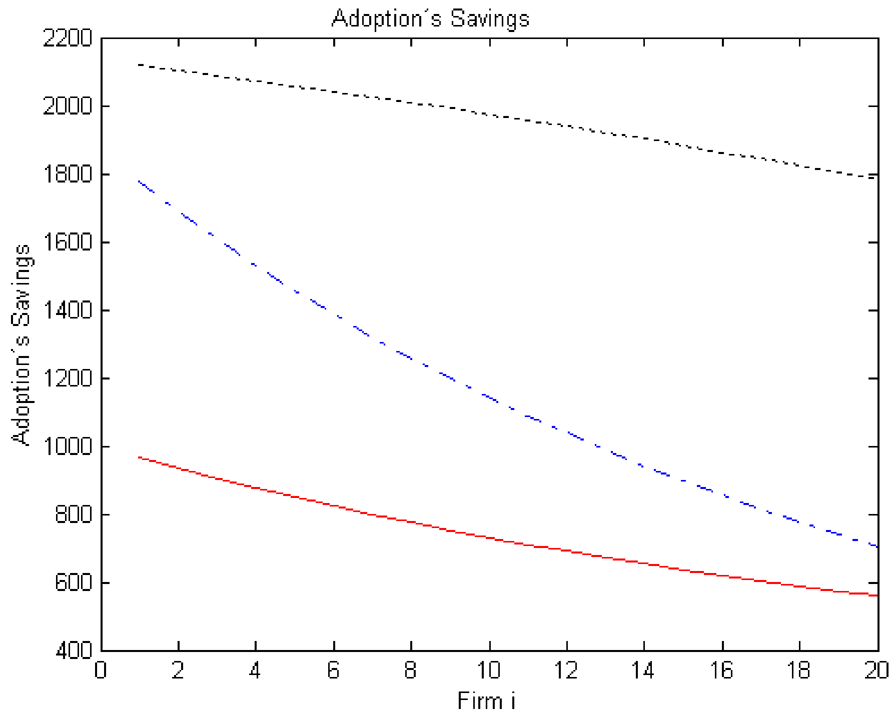

Figure N° 6: Adoption´s Savings

Figure N° 6 displays the adoption´s saving under each instrument. As expected, this flow is higher for marked based instruments, and particularly in the case of an emission tax. It can be seen that no matters the instrument, the sequence of adoption´s savings decreases, reflecting that late adopters will benefit less from adoption.

Figure N° 7 displays the adoption benefits due to the additional production induced by the emission standard and the tradable permit system. As expected, this flow is much more important in the case of the emission standard than under the tradable permit system, compensating the lower adoption´s savings. So, when both effects are considered, it can be seen that the emission standard works better than the tradable permit system inducing an early timing of adoption.

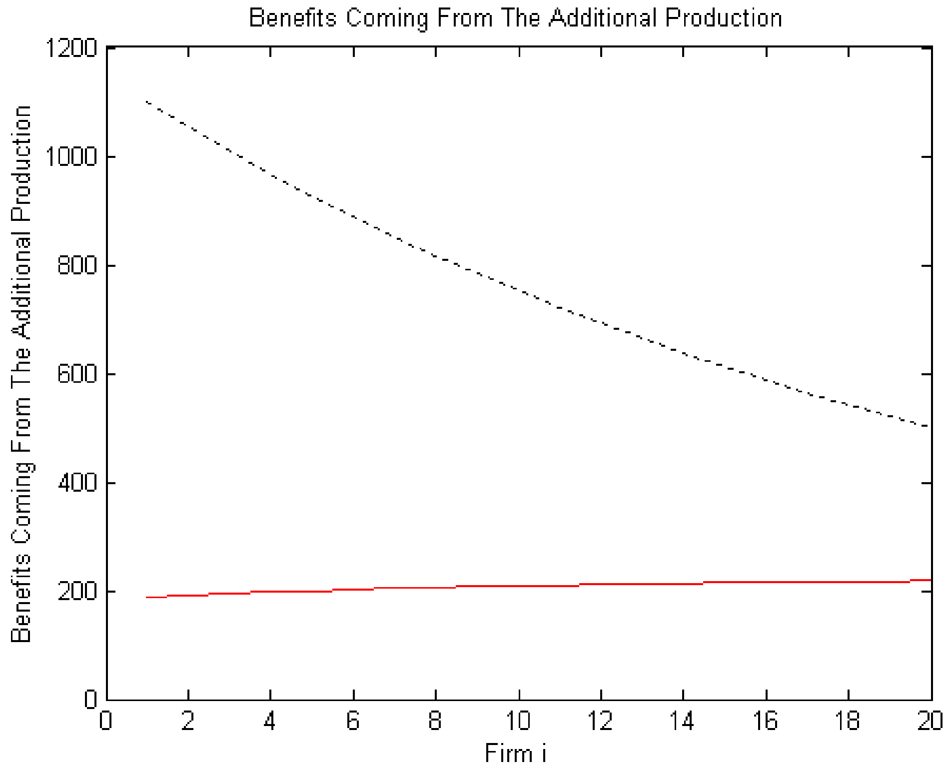

Figure N° 7: Benefits Coming From The Additional Production

3.4.1 Which is the optimal instrument to induce an earlier adoption?

In the previous sections it was explored how different environmental policies induce different patterns of adoption. However, determining which instrument is better requires to identify the present value of the welfare associated with each sequence. As each instrument induces very different dates of adoption, levels of production and profits, we should expect important differences in the welfare among policies. In fact, we have seen than the emission tax is the instrument inducing the fastest sequence of adoption but at the same time the least level of production. So changes in the producer surplus do not mean changes in the consumer surplus. On the other hand, the emission standard and the tradable permit system are less effective generating incentives to firms to upgrade their abatement technologies but create strong incentives to increase production and therefore to improve the consumer surplus.

The present value of the total welfare is defined as the present value of the sum of the consumer surplus plus the firms net profits. Given the demand curve and considering that at the date τ_i there are i firms using the new technology and $(N-i)$ using older ones, the present value of the consumer surplus CS when i firms have adopted can be characterized as:

$$CS(i) = \frac{b}{2} * \left[\sum_{m=1}^{m=i} q_{1m} + \sum_{m=i+1}^{m=N} q_{0m} \right]^2 * e^{-\delta\tau_i} \tag{3.20}$$

Where q_{1m} denotes the level of production of firms using the new technology and q_{0m} denotes the level of production of firms using the old technology. Using this last definition, the present of the total welfare W when i firms have adopted can be characterized as:

$$W(i) = CS(i) + \left[\sum_{m=1}^{i} \pi_{1m} + \sum_{m=i+1}^{N} \pi_{0m} - \sum_{m=1}^{i} e^{-\theta_i} * K \right] * e^{-\delta\tau_i} \tag{3.21}$$

Where π_{1m} denotes the profits of firms using the new technology and π_{0m} denotes the level of production of firms using the old technology.

Figure N° 8 displays the path of the present value of the consumer surplus. As expected, the emission standard produces the highest value for most of the sequence, while the tradable permit system produces the lowest one. In spite of the tradable permit system induces an increase in the global production after each technological upgrade, it takes so long under this policy to encourage early adopters to upgrade their technology that the discounted value of the extra production is even lower than the discounted level of the sequence of constant output induced by the emission tax.

Figure N° 8 shows that at some point in the sequence, the higher discount offset the additional production effect also in the case of the emission standard. In fact, the present value of the consumer surplus induced by the emission tax is higher after the technological upgrade of late adopters.

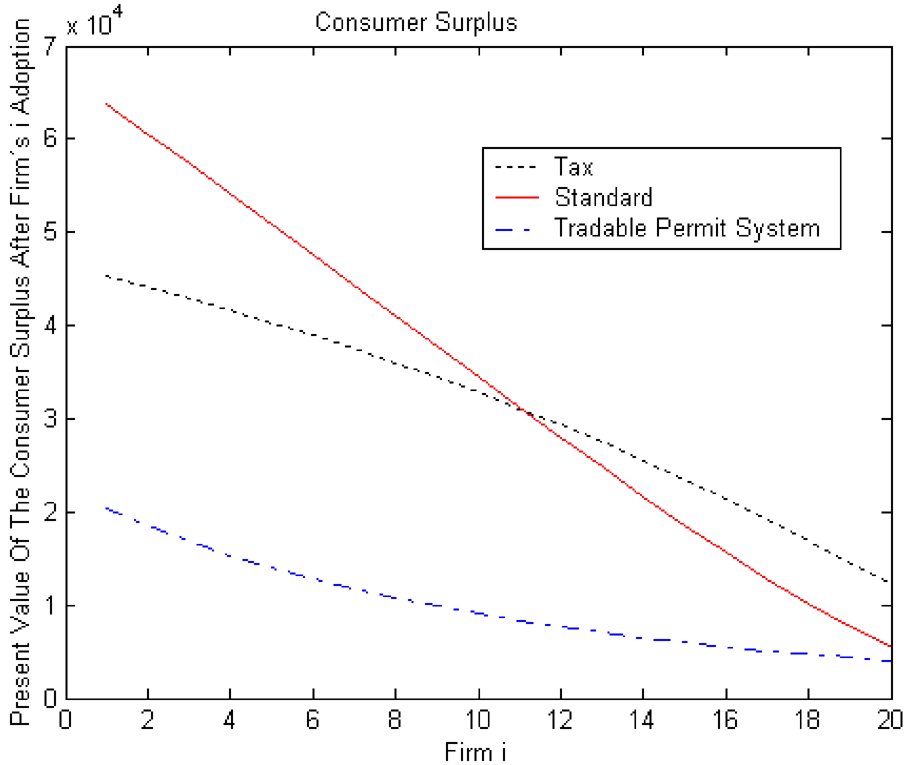

Figure N° 8: Consumer Surplus

Figure N° 9 displays the path of the present value of total welfare, that adds the effects of adoption in consumers and firms. We see that the emission standard produces the highest welfare for most of the sequence, followed by the emission tax while the tradable permit system induces the lowest.

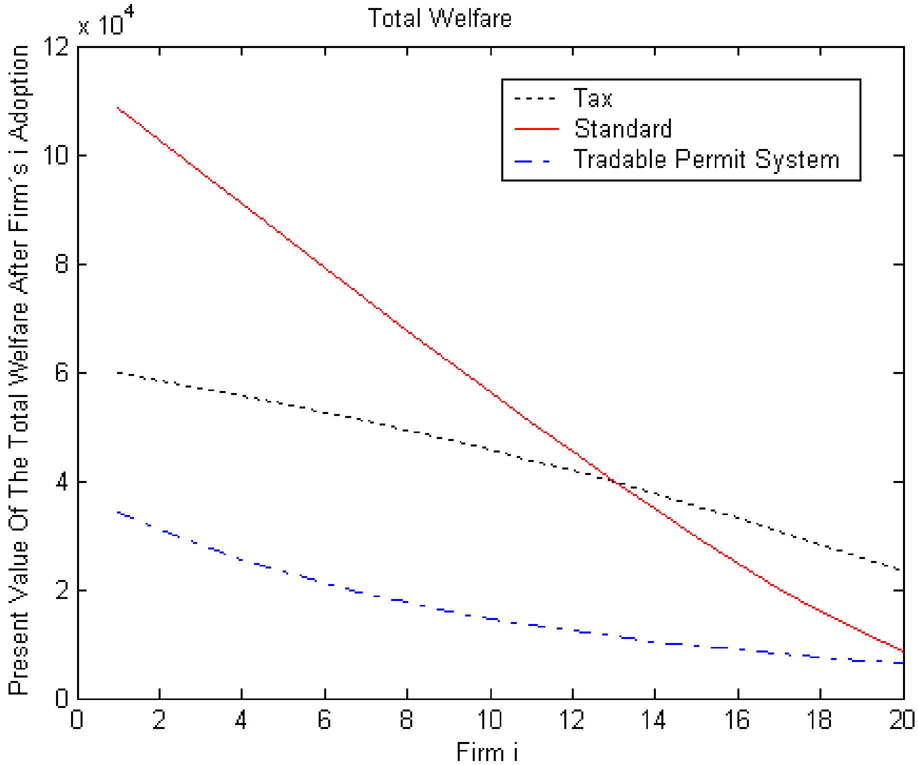

Figure N° 9: Total Welfare

Again, at some point in the sequence, the higher discount offset the greater welfare induced by the emission standard. So, to compare the total welfare produced by each instrument, it is necessary to calculate the present value of the total welfare produced over the entire sequence. Table N° 1 displays the results for different values of the price elasticty, since the timing of adoption strongly depends on this parameter. As it is shown in the Table, if the present value of the total welfare is the criteria to choose a policy instrument, the emission standard should be at the top the ranking, while the tradable permit system should be at the bottom. The superiority of the emission standard does not depend on the demand elasticity in the simulations, since in any case it produces the highest welfare.

Present Value Of Total Welfare					
	b = 0.5	b = 0.8	b = 1.0	b = 1.3	b = 1.5
Tax	2693800	931890	522700	240040	143790
Standard	3250800	1408600	881240	480910	339200
Tradable Permit System	2215000	372680	115740	19003	5195

Table N° 1: Present Value of Total Welfare

In sum, the numerical simulations suggest that policy makers looking for induce the earliest sequence of adoption of a new technology should prefer an emission tax. But if the total welfare is the criteria, an emission standard must be employed.

3.5 Conclusions

In this document it had been explored how different environmental policies affect the pattern of adoption of an environmentally friendly technology, concluding that an emission tax should be preferred by policymakers trying to induce the earliest sequence of adoption. However, in spite of this instrument grants firms with larger incentives to upgrade their abatement technologies does not produce the greatest social welfare. Since the tax is fixed, it does not provide firms with the flexibility to adapt to the new market conditions created by the technological change. In particular, firms do not have the incentives to increase production despite of that additional units of the final good could be produced profitably without adverse impacts in the environment.

On the other hand, we have seen than contrary to the usual belief that market based instruments provide better incentives than command and control policies, an emission standard works better inducing an optimal sequence of adoption than either a tax and a tradable permit system.

If well the timing of adoption could be affected by the environmental policy, it is also quite dependent on market conditions. Specifically, if the final product demand is more inelastic, all instruments would produce a slower sequence of adoption. The same happens with the cost heterogeneity among sources since if the new technology is profitable for any firm and there are not strong differences in their abatement costs, we should expect an almost instantaneous adoption.

The instrument ranking obtained in this paper runs strongly counter to most of the current literature on the relation between environmental policy and technological adoption, showing that there is no unique ranking and which instrument induces an earlier adoption and a greater welfare depends on several conditions, as for example, the market structure. In fact, most existing studies consider than the only flow of benefits of adoption corresponds to the savings in the total abatement cost. Once the technology is available, market based instruments would induce firms to reoptimize their level of abatement, so the savings using these instruments would the higher. Then, emission taxes should be preferred over tradable permit systems while emission standards should be at the bottom of the list. As the output of the firms is not considered, the instrument producing the early sequence of adoption would produce also the greatest welfare. However, under rivalry on the final product market, the firms´s incentives to produce are modified and a new flow of benefits of adoption must be considered. The profits obtained because of the increase in the output speed up the sequence of adoption under an emission standard and at the same time the total welfare induced by each instrument is modified.

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Chapter 4

Environmental Policy and the Timing of Technological Adoption in Santiago, Chile: The Natural Gas Case

4.1 Introduction

Technological change is maybe the main tool to face environmental problems in the long run. For that reason, the relation between technological change and environmental policy has received special attention because it is well known that environmental policy affects the incentives for firms to produce or to adopt a new technology, and through this mechanism, it affects the social cost of different policies. If a particular instrument can induce more R&D activities or an earlier adoption of cleaner technologies, it would be preferred for policy makers. However, the way an instrument modifies incentives is not clear and it could depend on several conditions.

Two areas of research have been explored in the literature: - one focused in understanding the potential of different policies to generate innovation and another concentrated in understanding how policies, that increase the economic incentives to reduce pollution affect the rate at which the existing technologies are adopted.

As Jaffre, Newell and Stavins (2000) pointed out, most of the work developed in both areas has been theoretical rather than empirical. However, the evidence generated from both approaches has been consistent with the finding that market-based instruments are likely to have significantly greater positive impacts than command and control policies to induce innovation or diffusion of desirable environmentally friendly technologies.

The aim of this study is to contribute to the knowledge of the second topic analyzing the case of natural gas adoption by stationary sources in Santiago, Chile. These sources have faced several environmental regulations encouraging the reduction of particulate matter´s emissions. In fact, a tradable permit system, a command and control policy and an environmental contingencies system have been applied since 1990. Switching to natural gas was a very simple way to meet such regulations and either due to this fact or due to its lower price, after two years from its introduction, this clean fuel was being used by almost 56% of the sources.

This experience offers a great opportunity to increase our understanding of the drivers behind the adoption of cleaner technologies and how this process could be affected by the environmental policy. The process is interesting because it is a broad and fast process of adoption. In addition, a non traditional instrument was applied which seems strongly correlated with the switching to natural gas[1]. Besides, it is a well documented experience of adoption for a developing country since the Chilean government has recorded the information about all stationary sources since early nineties to date through its Point Sources Emission Control Program (PROCEFF). Given that almost all the previous studies have been carried out for developed countries, this study will be the first generating empirical evidence about the effects of the environmental policy on adoption in an emerging country, where the lack of resources to develop innovations makes the option of bringing into use the innovations created in more advance countries the best alternative to comply the environmental regulations. However, the ability of environmental regulations to speed up the rate of adoption of such innovations in emerging countries is constrained by weak regulatory institutions. Then, whether or not the environmental policy encourages the adoption of desirable technologies will depend on the ability of policy makers to guarantee the compliance of the regulations.

The next section briefly synthesizes the previous empirical findings about the relation between environmental policy and technological adoption while section III describes Santiago's air pollution problem and outlines the main elements of the environmental regulation. Section IV describes the switching decision, the data available and the empirical methodology to be used. Section V presents the estimation results while section VI concludes.

4.2 Literature Review

The predominant theoretical framework to analyze how environmental policy instruments affect the adoption of new technologies has been the "discrete technology choice" model, where firms contemplate the use of a certain technology which reduces the marginal costs of pollution abatement and which has a known fixed cost associated with it. Firms must decide whether or not to use it evaluating the cost savings. Once the technology becomes available, market based instruments would induce firms to reoptimize their level of abatement, leading to higher cost savings, which tends to support their use over command and control policies

[1] This has led some authors to claim that this instrument was a major driver behind the fast adoption process. See Montero, Sánchez and Katz (2002).

There is little empirical evidence endorsing the theoretical findings about the effects of environmental policies. However, such studies are consistent with a better performance of market based instruments, particularly a tradable permit system over an emission standard. All the accumulated evidence refers to the United States´s case and there isn´t an equivalent study to evaluate the performance of such policies inducing adoption of an environmentally friendly technology in a developing country due the lack of reliable data.

To learn about the relation between technological change and environmental policy in a developing country could be quite important since to become a developed country should find ways to increase their productivity and competitiveness. The global convergence of environmental regulatory policies at a higher protective level, a trend imposed by richer countries, implies that it will become increasingly important to use environmentally friendly technologies in order to compete abroad. As most of these countries don't have enough resources to develop technological innovations, to bring into use the innovations created in more advanced countries seems to be the best alternative to comply. Besides, because of the existence of weak regulatory institutions, whether or not the environmental policy encourages the adoption of desirable technologies will depend on the ability of policy makers to guarantee the compliance of the regulations.

Nelissen and Requate (2004) and Jaffre, Newell and Stavins (2002) survey the empirical literature about the effects of environmental policies (taxes, a tradable system, standards and so on) inducing the adoption of available technologies. Most of the existing studies is focus on the adoption of energy efficient rather than in environmentally friendly technologies due to the fact that most of the pollution control experiences are fairly recent, and therefore there is lack of reliable data.

Related to energy efficiency, the work of Jaffre and Stavins (1995); Hasset and Metcalf (1995) and Greene (1990) can be highlighted.

Jaffe and Stavins (1995) analyze the factors affecting the adoption of thermal insulation technologies in new residential construction in United States between 1979 and 1998. They found that the decision to adopt this technology was more sensitive to changes in the adoption investment that to energy price changes. In a similar study, the results of Hasset and Metcalf (1995) agree with Jaffre and Stavins finding an even larger difference between the response to changes in installation cost and changes in energy prices.

Greene (1990) tested the relative effectiveness of CAFE[2] standards and gasoline prices in increasing fuel economy. For the three U.S. firms which faced CAFE standards, the regulation was more effective in incentivating fuel economy that gasoline prices increments. On the other hand, European firms base their fuel efficiency largely on market demand. For these firms CAFE standards were not even binding.

Kerr and Newell (2000), Keohane (2001), and Snyder, Miller and Stavins (2003) have explored the relation between abatement technologies and environmental policy.

[2]CAFE standards were created in 1978 with the purpose of reducing energy consumption by increasing the fuel economy of cars and light trucks.

Kerr and Newell (2001) assesses the effects of the phasedown program on technology diffusion in United Stated. The lead phasedown program was accomplished through a tradable permit system among refineries (where rights could be exchanged and/or banked for later use) and individually binding performance standards that limited the allowable content of lead in gasoline. In addition, a series of regulatory adjustments were made through time reducing the allowable content of lead. The authors found that decreasing the allowable content of lead encouraged adoption of technology. They also found that the tradable permit system provided more incentives for an efficient technology adoption decision, since the difference of the rate of adoption between low adoption cost firms and high adoption cost firms was larger under such an instrument.

In the context of the acid rain program, Keohane (2001) analyzes the effects of policy instruments in the selection of an abatement technology to remove sulfur dioxide. He found that the tradable permit system made the decision between a scrubber and fuel switching, more sensitive to cost differences than an emission standard.

Snyder, Miller and Stavins (2003) evaluated the effects of environmental regulation on the diffusion of membrane cell production technology in the chlorine manufacturing industry. They found that environmental regulations like the Montreal Protocol or the Toxic Release Inventory did affect the diffusion of the cleaner technology in the chlorine industry not by encouraging the adoption by existing facilities, but rather encouraging the shutdown of facilities using the environmentally inferior options.

This study is an attempt to understand the impacts of environmental policies over technological adoption in a developing country, considering the case of the stationary sources of air pollution in Santiago, Chile. These sources have faced several regulations encouraging the particulate matter emissions´s reductions. The policy mix implemented since 1990 includes a tradable permit system, a concentration standard and a contingencies system that forced to the dirtiest sources to shutdown during bad air quality episodes. The most common response to the decrease in the allowed pollution levels was to switch to natural gas, a cleaner fuel that began to be imported in Argentina in 1997. In a couple of years more than half of the stationary sources were using this fuel, raising questions about the drivers of such a fast adoption process, particularly because switching seemed to have several benefits for the sources. In fact, burning natural gas allows sources to meet the environmental regulations just as they reduced considerably the costs of the energy used in the production process. This paper attempts to disentangle the role of the drivers behind the adoption decision and to understand how the different environmental policies applied induced this switching process.

The focus of this paper is to understand the natural gas adoption process using the information recorded by the Point Sources Emission Control Program (PROCEFF). However, it is worth mentioning that PROCEFF´s database has been used previously with the objective of analyzing the performance of the tradable permit system applied in Santiago. Montero, Sánchez and Katz (2002) find that the emission permits market was not fully developed due to a combination of regulatory uncertainty, significant transactions costs and incomplete enforcement. They also highlight the economic incentives created by the grandfathering used to allocate the initial permits. According to them, this allocation mechanism encouraged incumbent sources to more readily declare their emissions and claim the corresponding permits. On the other hand, O´Ryan (2002) evaluates the impact of the introduction of natural gas in the applicability of the tradable permit system, suggesting that the availability of this fuel increased the range of emissions to be reduced at a low cost for most of the sources, reducing then the efficiency gains from using a market based instrument. Palacios and Chávez (2002) review the monitoring aspects of the tradable permit program and evaluate its performance in terms of enforcement, concluding that an aggregate level of over- compliance coexists with usual regulation violations from new sources. Finally, Coria (2006) describes the transactions that have taken place to date and how the development of the market has been affected by regulatory changes and market conditions, concluding that from the beginning of the system the quantity of emission permits granted has exceeded the sources´s requirements, producing a very significant excess of supply in spite of the regulatory changes that have reduced the mass of emission permits.

In the following section the Chilean regulatory system will be explained.

4.3 Chilean Environmental Regulation

The Chilean government has dealt with the air pollution problem in Santiago since the early 80´s. In 1996, Santiago was officially declared a non attainment zone by four atmospheric pollutants: - total suspended particles (TPS) – fine particulate matter (PM10), - carbon monoxide (CO), - and ozone (O3). Given that the worst adverse health effects have been produced by particulate matter[3], this pollutant has been the major focus of the regulation.

Due to their easy identification, the first efforts were devoted to control emissions coming from stationary sources. Chilean environmental authority distinguishes four types of stationary sources:

- Residential Boilers
- Industrial Boilers
- Industrial Processes
- Bakery Ovens

All these sources have been recorded through the Point Sources Emission Control Program (PROCEFF) who keeps an updated and permanent registry of all existing stationary

[3] There is a quite substantial amount of literature relating adverse health effects and particulate matter. Ostro, Sánchez and Eskeland (1996) found that the effects of particulate air pollution over premature death in Santiago were very similar to the adverse effects obtained in industrial countries, pointing out the importance of regulate such a pollutant in Santiago.

sources operating in Santiago. Table N^o 1 shows the contribution of each type of source to the total emissions generated from stationary sources.

Type of Stationary Source	N°	PM 10	
		Ton per Year	%
Industrial Processes	858	1467	46%
Industrial Boilers	979	1486	47%
Residential Boilers	1167	190	6%
Bakery Ovens	1459	33	1%
Total	4463	3175	100%

Source: Plan de Prevención y Descontaminación Atmosférica de la Región Metropolitana, 1997.

Table N^o 1: Contribution of Different Stationary Sources to Total Emissions

Current environmental law involving stationary sources rests mainly on two legal pieces: Supreme Decree 32 (promulgated in 1990) and Supreme Decree 4 (promulgated in 1992). These Decrees have been modified through Supreme Decree 16 (promulgated in 1998) and Supreme Decree 58 (promulgated in 2004). Next we synthesize the main regulatory elements contained in SD 32, SD 4 and their modifications.

SD 4 mostly controls boilers´s pollution (both industrial and residential).It distinguishes two kinds of sources:

- Large and small boilers, and
- Existing and new ones.

Large boilers are those with emissions discharged through a duct or stack at a maximum flow rate $\geq$ 1000 m3/hour while existing boilers are those installed or approved after 1992.

SD 4 established an individual cap for the emissions of large boilers and a tradable permit system that let this type of source to exceed this cap through the emission's offset with other large boilers. For that purpose, the existing large boilers were granted with emission permits while new large boilers were required to fully offset their emissions through the emissions abatement of existing large boilers.

Regarding the daily cap on emissions of existing large boilers, this was calculated according to the following formula:

Daily Emissions (kg/day) = Flow Rate(m^3/hr)*56(ug/m^3)*24(hours/day).

This means that each existing large boiler was allowed to emit daily a maximum given by the product of a target on emissions concentration equal to 56(ug/m^3) times the maximum flow rate (m^3/hr) of the gas existing the stack, assuming 24 hours of operation.

Modifications to SD 4 promulgated in 1998 and in 2004 reduced the quantity of allowed emissions to existing large boilers. In 2000 the target on emissions concentration was decreased to 50(ug/m^3), which meant a reduction of almost 10% of total allowed emissions. In 2005 it was reduced again to 32(ug/m^3), which meant that approximately an additional 26% of the initial allowed emissions were eliminated.

The offsetting rate was set up at 100% until 1998, and then it was increased to 120% and to 150% in 2000.

About the compensation system´s rules, each year PROCEFF must verify if the allowed emissions by each large boiler coincides with an estimation of its real emissions. If the estimated emissions exceed the emission permits, the large boiler must buy emission permits. If the emission permits exceed the estimated emissions, the difference can be sold or retained. All trades require approval by the regulatory agency, even those trades among large boilers that share common ownership. Additionally, large boilers are restricted to trade permits on either an annual or permanent basis.

For the rest of the sources (small boilers, bakery ovens and industrial processes), SD 4 established a standard on emissions concentration equal to 56ug / m^3 in 1997. In 2005, the standard was changed to 32ug / m^3 of particulate matter.

SD 32 regulates emissions from all stationary sources, during declared states of "environmental contingencies" of bad air quality. These episodes occur when an environmental quality index reaches certain values[4]. If the index reaches a value over 300, a "pre-emergency" episode is declared while if it reaches a value over 500 an "emergency" episode is declared.

SD 32 has been modified through the period under analysis. From 1990 to 2000, the environmental authority prepared every year a list that included all the stationary sources, ordering them according to its PM10´s emissions concentration. The source with the highest PM10´s concentration was at the top of the list while that source with the lowest PM10´s concentration was at the bottom. Those sources exhibiting the higher PM10´s concentration and held responsible for the 20% of the total mass emissions were included in the pre-emergency list and forced to shut down during a "pre-emergency" episode. Those sources exhibiting the higher PM10´s concentrations and held responsible for the 50% of the total mass of emissions were included in the emergency list and forced to shut down during an "emergency" episode. Obviously, those sources included in the pre-emergency list were also included in the emergency list.

In 1998, the proportion of firms forced to shut down during a "pre-emergency" was increased to 30% and in 2001 this regulation was redefined in terms of absolute pollution. Authority established a new threshold of 32 and 28 ug / m^3 of PM10´s emissions concentration to shut down the sources during pre-emergencies and emergencies, respectively.

Table N^o 2 shows the number of "pre-emergency" and "emergency" episodes declared

[4] To verify the fulfillment of the Chilean standard for particulate matter, the environmental authority measures the levels of PM10 per hour in a set of monitoring stations. The measuring are used to construct the environmental quality index ICAP that varies between 0 and 500.

during the period 1995-2005. As it can be seen, critical episodes have not been rare, so sources try to avoid being included in the contingencies lists. The pre-emergencies have been much more usual than emergencies.

Number of Environmental Contingencies 1995-2005											
Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Days in Pre-Emergency	2	6	13	12	14	11	4	11	5	2	2
Days in Emergency	0	0	0	1	1	0	0	0	0	0	0
Source: PROCEFF											

Table N° 2: Number of Environmental Contingencies

It must be mentioned that environmental contingencies are concentrated mostly during the winter season. This happens because Santiago's geography produces a thermal isolation layer during winter months that prevents pollution to leave the ground level.

Table N^o 3 synthesizes the regulations involving all kinds of sources. They can be classified into three categories: existing large boilers, new large boilers and non large boilers. SD 32 was made extensive to all these categories while SD 4 distinguishes between large and non large boilers. For non large boilers, SD 4 established a concentration standard that has changed through time. On the other hand, a tradable permit system was created to regulate large boilers. To grant the initial allowed emissions, large boilers were classified according to the date they started operations into existing and new ones. Existing large boilers received the initial allowed emissions while new large boilers were forced to fully compensate.

It was already mentioned that the most popular way to meet the regulation was to switch to natural gas, a clean fuel available since 1997 and imported from Argentina by a private company, METROGAS. After its arrival an intense process of adoption started. In 2005 almost 56% of all sources burned this fuel.

It is worth mentioning that natural gas was introduced through a gradual process of network construction going from 1997 to 2004 and more heavily concentrated between 1997 and 1998. As of 2006, its introduction to the whole city is not completed, but it is available in the most communes of Santiago.[See Annex N° 1 for details about the natural gas availability in Santiago´s communes]

The adoption process of natural gas coincides with and amazing reduction of stationary sources´s emissions. In fact, from 1997 to date PM10´s emissions have decreased almost 72% while the average concentration of this pollutant in their stacks has decreased 64%.

<table>
<tr><th>SD</th><th>Existing Large Boilers*</th><th>New Large Boilers**</th><th>Non Large Boilers***</th></tr>
<tr><td>SD 32 and Modifications</td><td colspan="3">1992: “Pre – Emergency List” if it belongs to those sources responsible for the 20% of the mass of emissions.
“Emergency List” if it belongs to those sources responsible for the 50% of the mass of emissions.
1998: “Pre – Emergency List” if it belongs to those sources responsible for the 30% of the mass of emissions.
To create the lists, sources are ordered according to their PM10´s concentration.

2001: Sources have to shut down during Pre – Emergencies and Emergencies if their concentration exceeds 32 and 28 ug / m3 of particulate matter, respectively.</td></tr>
<tr><td>SD 4 and Modifications</td><td>1997:
Cap to emissions equal to:
ED = Flow Rate * 24 * 0.000056.
Emissions over that cap can be offset with an emission’s reduction of other new or existing large boilers.
2000: The cap was modified to be compatible with a concentration target of 50ug/m3.
Permits above this new cap were taken away.
2005: The cap was modified to be compatible with a concentration target of 32ug/m3.
Permits above this new cap were taken away.</td><td>Must offset their emissions with a decrease of existing large boilers’s emissions. The ratio was set at 1 in 1992; 1.2 in 1998 and 1.5 in 2000.</td><td>1997: The maximum allowed concentration of particulate matter was set at 56ug / m3.

2005: The maximum allowed concentration of particulate matter was set up 32ug / m3.</td></tr>
<tr><td colspan="4">Source: Elaborated from SD 4, SD 32, SD 16 and SD 58.</td></tr>
</table>

*Industrial or residential boilers that discharge emissions at a flow rate equal or higher than 1000 m3/hour and that were active at 1992.

**Industrial or residential boilers that discharge emissions at a flow rate equal or higher than 1000 m3/hour and that started operations after 1992.

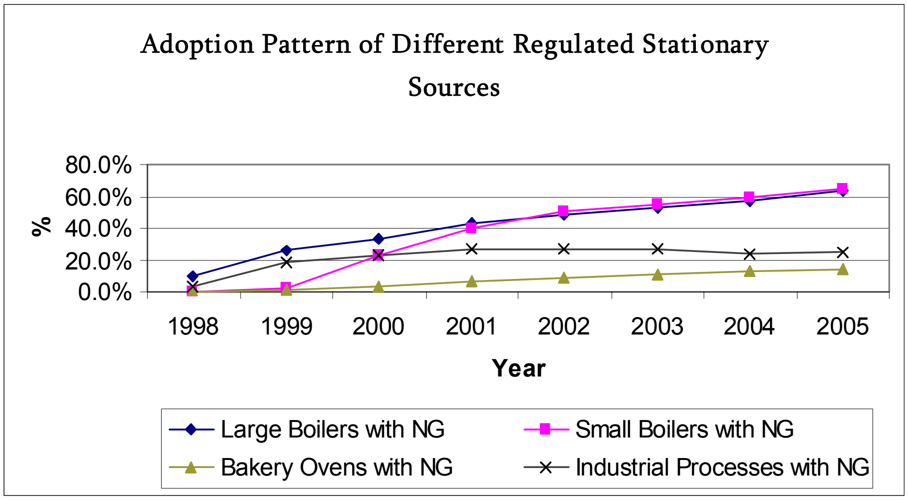
***Industrial or residential boilers that discharge emissions at a flow rate lower than 1000 m3/hour, bakery ovens and industrial processes.

Table N^o 3: A synthesis of Regulation Involving Stationary Sources.

Although many sources adopted natural gas fairly quickly, a large proportion of them have not yet switched and the pattern of adoption followed by the different types of stationary sources is very different, which suggests that the Chilean environmental regulation had some impact on the timing of adoption. Figure N^o 1 sketches the clear difference between the adoption patterns of boilers, either large or small, industrial processes and bakery ovens.

Large boilers started to adopt earlier while small boilers began to adopt heavily after 2000, catching up large boilers in 2001. Since then, boilers exhibited a very similar tendency of adoption and at the end of the period both groups showed a rate of adoption equal to 65%.

On the other hand, just a 14% of the bakery ovens used this fuel in 2005 while this proportion is a little higher an equal to 25% for industrial processes. Regarding the timing, industrial processes started the adoption process earlier than small boilers and bakery ovens, although its rate of adoption stayed almost the same since 1999.



Source: Elaborated from data provided by PROCEFF

Figure N° 1: Adoption Pattern of Different Stationary Sources

If the environmental regulation had some impact inducing the natural gas adoption, it is worth asking about the effectiveness of different instruments to encourage the change. At first sight, the similarity between the rate of adoption of large and small boilers suggests that the tradable permit system (a policy applied just to large boilers) was not very effective, while the contribution of the concentration standard (a policy applied to the rest) is not clear.

With regards to the contingencies system, Table N^o 4 displays the proportion of each type of stationary source included in the contingencies lists. About pre-emergencies, in 1997 a 52.48% of all sources in the list corresponded to large boilers, being the most affected group by this policy. This situation remained until 1999, when small boilers became the most affected group. Bakery ovens were not very affected while the relative importance of industrial processes within the list has increased since 2004.

Sources in the Contingencies Lists									
	1997	*1998*	*1999*	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*
Sources in the Pre-Emergency List									
Large Boilers	52.48%	40.00%	10.43%	6.29%	7.87%	7.74%	4.74%	8.99%	8.39%
Small Boilers	27.66%	33.48%	62.76%	75.85%	68.71%	67.56%	52.37%	5.06%	6.45%
Bakery Ovens	0.00%	4.78%	12.91%	4.85%	4.22%	8.04%	7.24%	0.00%	0.00%
Industrial Processes	19.9%	21.7%	13.9%	13.0%	19.2%	16.7%	35.7%	86.0%	85.2%
Pre-Emergency Concentration Threshold	92.9	77	35.4	30.1	32	32	32	32	32
Sources in the Emergency List									
Large Boilers	50.12%	18.94%	6.64%	6.20%	3.80%	3.33%	2.22%	1.70%	1.90%
Small Boilers	19.95%	53.89%	63.76%	55.09%	52.75%	47.15%	42.06%	37.12%	39.08%
Bakery Ovens	0.48%	4.96%	20.47%	27.18%	34.52%	42.05%	43.07%	46.91%	46.61%
Industrial Processes	29.45%	22.21%	9.13%	11.52%	8.93%	7.47%	12.64%	14.27%	12.42%
Emergency Concentration Threshold	63	50	28.9	22	28	28	28	28	28

Source: Elaborated from data provided by PROCEFF

Table N° 4: Sources in the Contingencies Lists

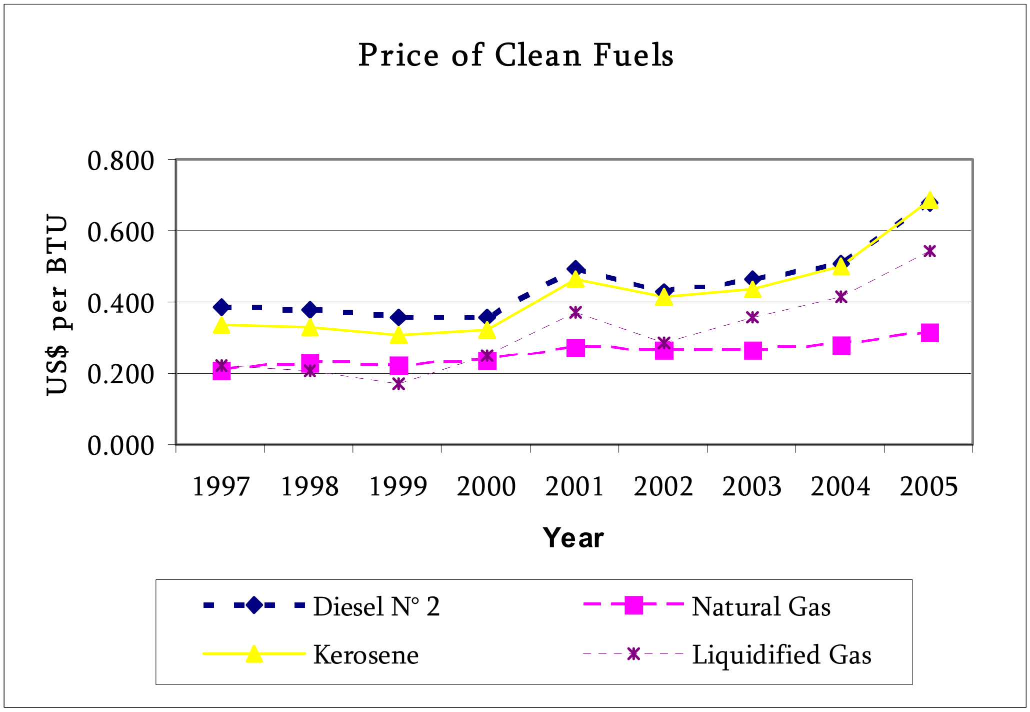
Small boilers and bakery ovens have been the most important groups in the emergency list through the time, except in 1997 and 1998 when large boilers were still important.

Pre-emergency and emergency episodes can be characterized as a zero emission standard for the subset of sources included in the lists. This standard is activated in days where meteorological conditions are very adverse, which is something outside sources control. In that sense, sources faced a huge uncertainty about the days in which a contingency would be declared. This uncertainty was increased by the way they were included in the program. Until 2001 the pre-emergency and emergency lists included the dirtiest 30% or 50% of all sources, respectively. Clearly, to belong to the lists depended not only on sources emissions decisions but also on the decision of the rest of the sources. Therefore, even taking measures to abate emissions could be not enough to avoid the lists if the rest of the sources abated more.

The criteria chosen to create the lists implied that every year it was necessary to emit less to avoid them. Table N^o 4 shows the concentration threshold to avoid to be included in each list. Until 1998, meeting the concentration standard of 56ug/m^3 seemed to be enough to avoid pre-emergencies, but after that, the stringency of this policy increased. The same happened with emergencies.

The relative importance of the different groups in the lists clearly coincides with the pattern of adoption. The take off of the adoption rate large boilers occurred when they were the most affected group and the same happened with small boilers. This suggests that SD 32 could have been very effective encouraging adoption. However, other factors that affect the switching could have varied during the period and therefore it is important to control for them in order to reach a conclusion.

As it was mentioned before, another important driver of the natural gas adoption could be its lower relative price with regards to the price of the rest of the clean fuels like kerosene, light oil or liquidified gas. Figure N° 2. displays the prices of these fuels per unit of energy.



Source: Elaborated from data provided by METROGAS, PROCEFF and The National Commission of Energy of Chile (CNE)

Figure N° 2: Price of Clean Fuels

It can be seen that depending on the fuel used previously, the switching could imply reductions on the per unit energy cost higher than 50%, being this a strong incentive to adopt. As the price´s gap increased over the period 1997-2005, the switching became increasingly more profitable.

So, the focus of this paper is to analyze the impacts of the different elements leading the adoption of natural gas in Santiago with the special objective of identifying the contribution of the regulatory instruments involved in SD 32 and SD4. The data employed for that was recorded by the Point Sources Emission Control Program (PROCEFF) and include information for more than 5.000 sources over 11 year (1995-2005). Industrial processes had to be exclude from the empirical analysis since there is no identification variable that allows to follow them through time. [5]

The next section introduces the elements behind the switching decision and the empirical model to be estimated to disentangle the impacts of the environmental regulations.

4.4 A Model of the Natural Gas Adoption Decision

4.4.1 The Switching Decision

To model the adoption of natural gas it is possible to assume that a representative source produces a given output at the time t using two inputs: energy (E) and capital (K). There are several types of energy that correspond to different fuels like crude oil, wood or coal. Let the energy produced at the time t through the fuel i be E_t^i .The capital input is specific to the fuel been used and is denoted by K^i. Thus the production of each source at the time t, depending on the fuel used, can be expressed as a function of these two inputs $X_t^i = X(E_t^i, K^i)$ where the assumed signs of the partial derivates are $X_{E_t^i} > 0, X_{K^i} \geq 0$. Fuels are traded at a market price z_t^i while W^i is the investment required to acquire the capital input.

The use of fuels has an external effect since produces a pollutant´s emissions. Each fuel produces emissions according to the function $e_t^i = h(E_t^i)$ with $\frac{\partial e_t^i}{\partial E_t^i} > 0$ and $\frac{\partial^2 e_t^i}{\partial^2 E_t^i} \geq 0$, which means that emissions are increasing in the use of fuels at a non-decreasing rate. Dirty fuels, like wood, coal or heavy oil produce more emissions than clean fuels as light oil, or liquidified gas for any level of use.

Emissions are regulated through different policy instruments depending on the size of the output produced by the source. Sources producing an average level of output higher than a threshold X^* -the large boilers- must compensate their emissions, trading emission permits at a price p_t. At the same time, all sources (either large boilers or non large boilers) emitting more than a threshold $\overline{\alpha_t}$ were included in the contingencies system at the time t and forced to shutdown during critical episodes that occurred with probability μ_t.[6]

Sources must make efforts to reduce their pollution if they wanted to avoid the environmental regulation. Attempts to cut back on emissions could involve: a reduction in the use of inputs and therefore in the level of production, leaving the market or switching from a dirtier to a cleaner fuel.[7] The natural gas switching decision can be considered then as a

[5] It is fair to say that industrial processes seem a very interesting group because rather than switching their fuel, they responded to the environmental regulation installing more complex abatement technologies. Over the period under analysis the fraction of them using such technologies increased from 35% to 53% while in the case of the rest of the sources this rate was very low.

[6] The concentration standard applied to the non large boilers was omitted of this analysis since due to the linear relation between emissions and pollution, it implied in practice to emit less than a threshold $\overline{\delta}$ that exceeded the threshold $\overline{\alpha}$ for most of the period, as it can be seen in Table N° 4.

[7] Sources could also reduce their emissions installing end-of-pipe technologies such as filters, electrostatic precipitators, cyclones or scrubbers. However, this was very unusual. In fact, sources preferred switching fuel instead and only a 5% of the sample (excluding industrial processes) installed such technologies in

situation where one of the cleanest fuels that currently exists become available to sources at some point in the sample and each source should decide whether to adopt it or not and the date of adoption, considering the benefits and costs.

There were three different benefits of the switching to natural gas in this model. First, it allowed sources to leave the contingencies system since its level of emissions e_t^{NG} was lower than the threshold $\overline{\alpha_t}$ at any time. Second, it reduced the cost of the required energy due to the differences in fuel´s market prices. Finally, the lower level of emissions produced for this fuel e_t^{NG} allowed large boilers to reduce the number of emission permits used e_t^i.

Let π^0 be the source´s profit without natural gas and π^1 be the profit after the switching (gross of the investment required to acquire the capital input). Each source is a profit maximizer that chooses the date of adoption T to solve the following dynamic optimization problem:

$$\max_T \int_0^T \pi^0(\overline{\alpha_t}, \mu_t, z_t, p_t, C_t)e^{-rT} + \int_T^\infty \pi^1(\overline{\alpha_t}, \mu_t, z_t, p_t, C_t)e^{-rT} - W^{NG}e^{-rT} \tag{4.1}$$

where C_t is a vector of source-specific characteristics that may affect the benefits of adoption, z_t is the vector of fuel prices and r is the intertemporal discount rate.

The solution to this problem leads to the following arbitrage condition:

$$\pi^1(\overline{\alpha_t}, \mu_t, z_t, z_t^{NG}, p_t, C_t^i) - \pi^0(\overline{\alpha_t}, \mu_t, z_t, z_t^{NG}, p_t, C_t^i) = r * W^{NG} \tag{4.2}$$

So, the representative source will switch to natural gas when the costs of delaying the switching equals the benefits. The costs of delaying correspond to the difference in the profit flows, while the benefits of postponing is equal to the opportunity cost of saving the initial investment. When both elements are equal, the source switches.

Let´s assume that for the representative source the cost of being closed at the time t corresponds to L_t, that z_t^{NG} denotes the market price of the natural gas while W^{NG} is investment required to acquire the capital input necessary to burn it. Let the variable d_t indicate if the source was included in the contingencies program at the time t or not, taking a value equal to one if it was included and zero otherwise. Then, it is possible to characterize the arbitrage equation in the case of non large boilers through the following formula:

$$\mu_t * d_t * L_t + X_t^i(z_t^i - z_t^{NG}) = r * W^{NG} \tag{4.3}$$

Thus, the non large boilers included in the contingencies system would switch to natural gas insofar the expected benefits from avoiding the shutdown plus any gain in the energy expenditure compensate the oportunity cost of the required investment to bring natural gas

practice.

into use. In the meantime, the non large boilers that were not included in the contingencies system would switch insofar the gains in the energy expenditure compensate the oportunity cost of the investment.

The previous analysis is slightly different in the case of large boilers since an additional flow of benefits is added. In fact, the third term in equation 4.4 represents the savings due to the reduction in the use of emission permits.

$$\mu_t * d_t * L + X_t^i(z_t^i - z_t^{NG}) + p_t(e_t^i - e_t^{NG}) = r * W^{NG} \tag{4.4}$$

Let the indicator variable *permit* denote large boilers, taking a value equal to one for those sources producing an average level of output higher than the threshold X^* and zero otherwise. Then, it is possible to represent the arbitrage equation for any source through the following general formula:

$$\mu_t * d_t * L + X_t^i(z_t^i - z_t^{NG}) + permit * p_t * (e_t^i - e_t^{NG}) = r * W^{NG} \tag{4.5}$$

Equation 4.5 allows to disentagle the main drivers behind the adoption decision: the savings in the cost of the environmental regulation and the savings in the cost of the required energy.

Following, I detail the variables included in the econometric model that try to capture such drivers in the empirical analysis of the switching decision.

4.4.2 The Econometric Model

The analysis of the switching decision suggests the need of formulating the adoption problem in dynamic terms since the explanatory variables are changing over time. In fact, the effects of changes in the natural gas relative price and on the stringency of the regulation must be captured through the estimation methodology. Hazard models help to deal with dynamic issues because they allow to incorporate the variation of such variables and to estimate how their variation modifies the adoption decision. Therefore, with this methodology it is possible to disentangle the contribution of the explanatory variables on the switching decision but also on the adoption spells and their durations.

Indeed, the hazard function for each firm is defined as the probability of adopting the technology at time t given that it has not yet been adopted. Formally:

$$h(t, x_t, \beta) = \frac{f(t, x_t, \beta)}{1 - F(t, x_t, \beta)} \tag{4.6}$$

Where $f(t, x_t, \beta)$ is the probability density for adoption and $F(t, x_t, \beta)$ is the cumulative distribution function specifying the probability that the random variable T (time until adoption) is less than some value t, x_t is a set of explanatory variables which may change over time and β is a set of parameters to be estimated.

The behavior of the hazard function over time depends on the distributional assumptions for $F(t, x_t, \beta)$ and on the way that the explanatory variables x_t change over time. The parameters β can be estimated using maximum likelihood.

Previous studies analyzing technological adoption have explored a variety of continuos time specifications like Exponential, Weibull or Gompertz for $F(t, x_t, \beta)$. However, in the case studied here data are intrinsically discrete. If well adoption occurs in continuous time, the data are not observed in that form, but rather spell lengths are observed only in intervals of a year and unfortunately, the experiment is not so long to assume a continuos approximation[8]. Thus, trying to reflect the nature of the data available, the two leading cases are explored: - the logistic and the complementary log-log. The complementary log-log specification is a discrete representation of a continuous time proportional hazard model while the logistic model was primarily developed for data that is intrinsically discrete.

Both specifications separate the effects of explanatory variables on the hazard rate into two components: a baseline hazard rate which is a function of time, $c(t)$ and a function of the covariates $\beta' x_t$. Let $z(t) = c(t) + \beta' x_t$ for a representative source in year t.Then, the shapes of the logistic and complementary log-log time hazard functions correspond to:

$$h^{Logistic}(t, x_t, \beta) = [1 + \exp(-z(t))]^{-1} \tag{4.7}$$

$$h^{C \log \log}(t, x_t, \beta) = 1 - \exp[-\exp(z(t))] \tag{4.8}$$

In both models all differences between sources are assumed to be captured through the covariates. However, generalizations of them can be considered to allow for unobserved individual effects. In such a case, an unobservable variable v scales the non heterogeneous hazard rate component $h(t, x_t, \beta | v) = v * h(t, x_t, \beta)$, where the random variables v is assumed to have the following properties: $v > 0$,$E(v) = 1$[9], finite variance σ^2 and distributed independently of t and x_t.

Clearly, it is not possible to estimate the values of v themselves since, by construction, they are not observed However, assuming that the distribution of v has a shape whose functional form is summarized in terms of only a few parameters, it is possible to estimate those parameters with the data available. The most commonly used specifications are the Normal and the Gamma distribution. The last one is used in this study.

Regarding the choice of shape of the duration dependence specification $c(t)$, it is up to the researcher to choose between parametric and non parametric functional forms. The model estimated assumes a non-parametric baseline, creating duration-interval-specific dummy variables, one for each spell year at risk. This approach was chosen because, as a practical matter, the accuracy of the estimator is better for shorter durations. Besides, this formulation allows the data to reflect any shock occurred in a particular year. This is quite relevant in the natural gas case, since Chile has faced, from 2004 onwards,

[8] Kerr and Newell (2001) use data on 378 refineries over 25 years, while Snyder, Miller and Stavins(2003) examine 55 facilities from 1976 to 2001. Data used in this paper is on more than 5000 sources, which are observed for 8 years, since natural gas became available only in 1998.

[9] Unit mean (a normalisation) is required for identification.

restrictions over the quantity of gas that can be imported from Argentina, which is its only supplier.

The dependent variable $\underline{NATURALGAS_t}$ indicates whether a source has adopted natural gas at each point in time within sample or not, taking a value equal to one if the source is using natural gas at the time t and zero otherwise. The covariates used to explain $NATURALGAS_t$ are the following:

Economic Variables

Size: Theory suggests that bigger sources should adopt faster due to a stronger financial support or to the existence of scale economies. The variable FlowRate_t, is a proxy of the second effect. FlowRate_t is defined as the rate at which emissions are discharged through a duct or stack at t and it is strongly correlated with the size of the combustion process. However, it is also strongly correlated with the type of the policy instrument since those sources discharging their emissions at a rate higher than 1000 $m^3/hour$ are regulated through the tradable permit system. So, to be able to disentangle the effect of size from the regulatory effect, five flow rate dummy variables are created to reduce the correlation between both variables. The dummies are defined as follows: FlowRate_t^1 takes a value equal to one if the source discharged its emissions at a rate lower than 500 $m^3/hour$ and zero otherwise; FlowRate_t^2 takes a value equal to one if the source discharged its emissions at a rate between $500-1200$ $m^3/hour$ and zero otherwise; FlowRate_t^3 takes a value equal to one if the rate varies between 1200 and 1900 $m^3/hour$ and zero otherwise; FlowRate_t^4 takes a value equal to one if the rate varies between 1900 and 3500 $m^3/hour$ and zero otherwise. Finally, FlowRate_t^5 takes a value of one if the rate is higher than 3500 $m^3/hour$ and zero otherwise. All the coefficients are expected to be positive and statistically significant.

Previous Change: From the analysis of the switching decision it is clear that those sources burning cleaner fuels face less regulatory restrictions than those using dirtier fuels. In addition, there could be opportunity costs created by the previous switching. So, those sources that switched to cleaner non natural gas at some point in the sample could be less prone to switch again since the benefits will be lower and the capital costs will be greater. The dummy variable PreviousChange takes account of this effect. It takes a value equal to one if the source switched to a cleaner non natural gas fuel before the natural gas arrival or during the experiment and zero otherwise. This coefficient is expect to be negative and statistically significant.

Equipment: Sources could also reduce their emissions installing end-of-pipe technologies such as filters, electrostatic precipitators, cyclones or scrubbers. However, in the sample, this was a very unusual alternative. The dummy variable Equipment is included to capture any effect that the availability of abatement technologies could have on the switching probability.

Type: The main reason to include fixed effects is to capture any difference in the pattern of adoption among sources not explained by the rest of the covariates. One important reason to expect such differences regards the uneven monitoring and enforcement efforts that the environmental authority carried out to verify the regulation compliance. As it can be seen in Table N° 5, such efforts varied very much with the type. In fact, industrial sources were much more prone to be inspected than residential boilers or bakery ovens.

Differences in the monitoring and enforcement activities across sources must produce differences in the importance of the different flows of benefit coming from the switching. Particularly, the benefits of avoiding the contingencies system must be greater for those sources that are more prone to be inspected because the expected cost of being closed are greater.

Thus, fixed effects are expected to be significant explaining the adoption patterns. The dummy variables $\mathrm{Re}\,sidentialBoiler$ [that is equal to one for residential boilers and zero otherwise] and $Ba\ker yOven$ [that is equal to one for bakery ovens and zero otherwise] are included to capture fixed effects by type.

Proportion of Stationary Sources Inspected by Group				
Type of Source	Year			
	2000	2001	2002	2003
Industrial Boilers	74.0%	73.8%	95.1%	96.8%
Residential Boilers	27.7%	30.7%	31.0%	51.7%
Bakery Ovens	30.16%	44.04%	23.14%	21.27%

Source: Elaborated from data provided by PROCEFF

Table N° 5: Proportion of Stationary Sources Inspected by Group

Fuel Prices Gap: Switching fuels affects production costs since each fuel entails a different per unit energy cost, either because of differences in the fuel price or in the quantity required to generate the same level of production. Additionally, the natural gas supplier METROGAS uses a non linear pricing scheme, combining an average per cubic meter fee that decreases with the volume with a fixed charge that increases with it.[See Annex N° 2 for a description of the pricing scheme used by METROGAS].

So, all these dimensions need to be included in the construction of a meaningful variable able to catch up whether or not the switching´s cost advantages can explain the pattern of adoption. For this end, a relative price variable, by source per year, considering the fuel the source was using previously was constructed. Assume a source was burning fuel i to produce a quantity of energy equal to X. To produce such a quantity X^i cubic meters of fuel i are required while if it uses natural gas, X^{NG} cubic meters are needed Then, the relative price at t corresponds to the ratio between the expenditure in energy using fuel i and the expenditure if it were burning natural gas in that particular year, as it is detailed in the following formula.

$$Fuel\Pr ice_t^i = \frac{EnergyExpediture_t^i}{EnergyExpediture_t^{NG}} = \frac{z_t^i * X_t^i}{z_t^{NG}(X_t^{NG}) * X_t^{NG} + FixedCh\arg e_t(X_t^{NG})} \tag{4.9}$$

Where the expenditure in gas is equal to the price of that fuel for that level of consumption $z_t^{NG}(X_t^{NG})$ times the level of consumption plus the fixed charge, which also depends on the volume of natural gas used by the source $FixedCh\arg e_t(X_t^{NG})$.[10]

Due to data limitations, the analysis focused in the most used fuels of the sample, dropping all the sources burning other type of fuels. Fortunately, I did not miss many observations, as it can be seen in Table N° 6 that details the fuels kept and the proportion of stationary sources in the sample burning them. Therefore, the variable $Fuel\Pr ice_t^i$ was created for those sources using Diesel N° 5, Diesel N° 2, Liquidified Gas, Kerosene and City Gas.

Fuel (%)	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Diesel № 5	15.22	11.45	4.89	2.34	0.41	0.23	0.05	0.1	0.07	0.02	0.06
Diesel № 2	56.70	64.79	75.38	78.45	78.70	64.16	48.84	42.59	40.67	37.55	31.40
Liquefied Gas	3.82	6.09	7.49	7.97	8.16	10.12	13.12	12.74	12.73	13.15	12.3
Kerosene	3.35	3.41	2.85	2.60	1.85	1.42	1.20	0.98	0.78	0.69	0.52
City Gas	1.82	1.64	2.59	2.47	2.25	2.11	2.35	2.93	2.90	2.83	3.86
Natural Gas			0.04	2.41	7.13	21.15	33.69	40.15	42.35	45.15	51.17
% Total	80.91	87.38	93.24	96.24	98.5	99.19	99.25	99.49	99.50	99.39	99.31
N° of Sources	1915	2109	2602	2966	3078	3320	3521	3750	3970	4212	5249

Source: Elaborated from data provided by PROCEFF

Table N° 6: Stationary Sources´s Fuel Shares

[10] In data set the information about energy consumption is expressed in kilograms by hour, so multiplying the original variable times the number of hours a source works everyday and times the number of days that works every month, the consumption by month by source is determined.Then, times this consumption by month is transformed into m3 of fuel dividing by the density of each fuel. After that, the physical consumption is expressed in money and the relative price is calculated.

Fuel Price^i_t	1998	1999	2000	2001	2002	2003	2004	2005
Diesel N° 2	2.16	2.06	1.86	1.61	1.77	1.68	1.82	1.89
Diesel N° 5	0.96	0.73	0.92	1.13	1.02	0.98	1.10	1.15
Liquidified Gas	2.36	2.06	1.61	2.1	2.5	2.13	2.67	2.81
Kerosene	1.82	1.67	1.53	1.40	1.68	1.60	1.64	1.75
City Gas	2.94	2.74	2.12	2.06	1.67	1.52	1.60	1.69

Source: Elaborated from data provided by PROCEFF

Table N° 7: Fuel Relative Prices

Table N° 7 shows that there were significant cost savings from switching, since the energy expenditure could be reduced to a half in most years. So, $Fuel\,\Pr ice_t$ is expected to be positive and statistically significant.

Regulatory Variables

As it has already been mentioned previously, stationary sources in the sample are regulated through three different policy instruments: - a tradable permit system, - a concentration standard and an environmental contingencies system that forces sources to shutdown during critical air quality episodes. So, to capture the impact of the environmental policy, the following variables are included:

Permit: This is a dummy variable that takes a value of one if the source is regulated through the tradable permit system and zero otherwise. The analysis of the switching decision suggests that being a source regulated through this system increases the benefits adoption due to reduction in the use of emission permits. Then, this coefficient is expected to be positive and statistically significant.[11]

Number of Shutdowns$_{t-1}$: Sources adopting natural gas as a response to the contingencies system were trying to avoid the shutdowns induced by the lists. More shutdowns increase the economic benefits from adoption. So, to capture the impacts of critical episodes, the variable *Number of Shutdowns*$_{t-1}$ is included. It equals the number of days that the sources included either in the Pre-Emergency or Emergency list, or both, had to close the previous year due to these regulations:

$$\begin{aligned} Number of Shutdowns_{t-1} &= \Pr e - Emergency_{t-1} * N^{\circ} of \Pr e - Emergecies_{t-1} + \quad (4.10) \\ & \quad Emergency_{t-1} * N^{\circ} of Emergecies_{t-1} \end{aligned}$$

[11] To give account of the impacts of the tradable permit system, other specification of the regulatory variable *Permit* was tried. This was the variable *DeltaEmisiones* that corresponded to the difference between the emissions produced by cleaner non natural gas fuels and the emissions produced by natural gas. However, the estimation results of the hazard model using such a variable did not change.

The lagged value of the variable is used since this should be the best guess available to sources deciding whether or not to switch to natural gas at the beginning of each interval at risk[12].If the cost of being closed is important, $\textit{Number of Shutdowns}_{t-1}$ should be positive and statistically significant.

The variables *Permit* and $\textit{Number of Shutdowns}_{t-1}$ are expected to capture the impacts of the different regulations. *Permit* should pick up any effect that the tradable permit system had beyond the concentration standard while $\textit{Number of Shutdowns}_{t-1}$ should pick up any effect that the contingencies system had beyond the traditional instruments.

The standard procedure to estimate discrete hazard models requires to re-organize the data set so that for each source there are as many rows as there are intervals at risk of the event occurring for each source. So, the panel was turned from one with one row of data per source to another in which each source contributes T_i rows, where T_i is the number of years i was at risk of adoption. T_i is denoted as "$\textit{Study Time}_i$". For a source that switched to natural gas, "*Study Time*" corresponds to the time until adoption. If it never changed, it corresponds to the time the source survives in the experiment. However, it cannot be expect sources to switch to natural gas if this fuel was not available. Thus, the number of years at risk of adoption of sources located in communes where natural gas was available after 1998 starts to be considered from the date at which natural gas entered to that commune. As an example, consider the case of a source that existed in 1998 but only had gas available in 2000 and switched to it in 2003. Then, for this source "*Study Time*" equals three.

Table N° 8 presents summary statistics of the covariates for the whole sample and Table N° 8 presents summary statistics for subsamples of stationary sources (industrial boilers, residential boilers and bakery ovens) and for subsamples of adopters and non adopters.

[12] Other specifications to give account of the impacts of the contingencies system were also tried. For example, the variables Pre-$\textit{Emergency}_{t-1}$ and $\textit{Emergency}_{t-1}$, where Pre-$\textit{Emergency}_{t-1}$ was a dummy variable equal to one if the source was included in the pre-emergency list the previous year and zero otherwise and $\textit{Emergency}_{t-1}$was a dummy variable equal to one if the source was included in the pre-emergency list the previous year and zero otherwise. However, the estimation results of the hazard model using such variables did not change, so this specification was kept as it is more meaningful and consistent with the decision rule obtained from the switching model.

Variable	N° Obs.	Mean	Std. Dev.	Min	Max
NG_t	19618	0.105	0.307	0	1
N° of $Shutdowns_{t-1}$	15284	1.964	4.321	0	15
Industrial Boilers	19930	0.232	0.426	0	1
Residential Boilers	19930	0.488	0.499	0	1
Bakery Ovens	19930	0.280	0.448	0	1
Fuel $Price_t$	16966	1.918	0.468	0.45	3.57
Permit	19618	0.117	0.321	0	1
$FlowRate^1_t$	19618	0.717	0.450	0	1
$FlowRate^2_t$	19618	0.200	0.399	0	1
$FlowRate^3_t$	19618	0.033	0.179	0	1
$FlowRate^4_t$	19618	0.032	0.177	0	1
$FlowRate^5_t$	19618	0.018	0.133	1	1
Previous Change	19618	0.194	0.394	0	1
$Equipment_t$	19618	0.012	0.106	0	1
Baseline					
Dummy1998	19618	0.095	0.294	0	1
Dummy1999	19618	0.110	0.327	0	1
Dummy2000	19618	0.140	0.348	0	1
Dummy2001	19618	0.132	0.339	0	1
Dummy2002	19618	0.130	0.337	0	1
Dummy2003	19618	0.114	0.318	0	1
Dummy2004	19618	0.123	0.329	0	1
Dummy2005	19618	0.151	0.358	0	1
Study Time	19618	6.44	2.26	1	8

Table N° 8: Summary Statistics

Variable	Industrial Boilers		Residencial Boilers		Bakery Ovens	
	Changed	Did Not Change	Changed	Did Not Change	Changed	Did Not Change
	Mean		Mean		Mean	
NG_t	0.0687		0.184		0.0260	
N° of $Shutdowns_{t-1}$	1.950	1.899	3.400	2.558	1.282	0.700
Fuel $Price_t$	2.140	2.012	1.954	1.830	2.041	1.906
Permit	0.608	0.316	0.046	0.073		
$FlowRate^1_t$	0.163	0.445	0.705	0.763	0.958	0.933
$FlowRate^2_t$	0.335	0.322	0.274	0.189	0.022	0.064
$FlowRate^3_t$	0.164	0.095	0.007	0.020	0.012	0.001
$FlowRate^4_t$	0.200	0.088	0.010	0.017	0.006	0.000
$FlowRate^5_t$	0.135	0.048	0.002	0.009	0.000	0.000
Previous Change	0.140	0.369	0.014	0.138	0.019	0.258
$Equipment_t$	0.018	0.014	0.004	0.003	0.019	0.021
Baseline						
Dummy1998	0.261	0.098	0.114	0.081	0.118	0.073
Dummy1999	0.232	0.108	0.148	0.089	0.128	0.090
Dummy2000	0.181	0.122	0.232	0.119	0.182	0.114
Dummy2001	0.142	0.126	0.164	0.124	0.163	0.123
Dummy2002	0.079	0.134	0.099	0.138	0.128	0.146
Dummy2003	0.044	0.128	0.056	0.130	0.092	0.133
Dummy2004	0.029	0.135	0.042	0.144	0.112	0.156
Dummy2005	0.028	0.145	0.142	0.171	0.073	0.160
Study Time	3.57	7.61	3.54	7.26	3.57	7.03

Table N° 9: Summary Statistics by Group

4.5 Estimation Results

The results of the estimation of the hazard model for the adoption decision are presented in Table N° 10 and Table N° 11. Table N° 10 displays the results of the hazard model disentangling the effects of the contingencies for the logit, the complementary log-log and the Gamma specification while Table N° 11 displays the results for type of stationary source, separating among industrial boilers, residential boilers and bakery ovens. The results reported are not the estimated values of the coefficients, but rather the exponentiated coefficients. Due to the non-linear nature of the hazard function, interpreting the results is not straightforward. However, in simple terms, an exponentiated coefficient greater than 1.0 indicates than an increase in the covariate increases the baseline hazard. On the contrary, an exponentiated coefficient less than 1.0 indicates that the variable decreases the baseline hazard.

As it will be shown, results are robust to different specifications, and in most cases the sign and significance of the coefficients is the expected.

The estimations show that the bigger sources $[FlowRate^3, FlowRate^4$ and $FlowRate^5]$ were more likely to switch to natural gas. On the contrary, to have switched to another cleaner non natural gas fuel $[\Pr eviousChange]$ decreases the probability of change.

As expected, $Fuel \Pr ice$ is positive and statistically significant, suggesting the existence of important cost advantages of switching to natural gas. $Permit$ and $N^{\circ} of Shutdowns_{t-1}$ have the expected signs, although surprisingly none affects statistically the likelihood of switching when the entire sample is considered.

The results are consistent with a significant fixed effect by group that indicates that being a residential boiler increases the adoption probability while being a bakery oven decreases it. This suggest that independently of the rest of the variables considered in the analysis, residential boilers did adopt more while the contrary happens with bakery ovens.

Regarding the baseline, the results indicate that from 2002 onward the stationary sources began to adopt at a lower rate. A possible explanation to this fact is that the dummies are capturing some sort of vintage effect. Since the sources that did not switch (probably since they did not have enough benefits of adoption) are those that remain more time in the sample, the negative coefficients are showing that each year the adoption is less probable for them. This situation can also be related to the natural gas crisis that began in 2004 due to the restrictions imposed by the Argentinian government to the quantity of this fuel that can be imported by Chile. Clearly, the crisis reduced the incentives to switch given the uncertainty about the availability of this fuel.

The logit and the complementary log-log specification suggest that to have at one's disposal abatement equipment $[Equipment]$ affects positively the adoption probability, but not significantly. However, the Gamma specification suggest a positive and significant effect. As it was already mentioned, there are few sources in the sample using such equipment. The result obtained with the the Gamma specification is very particular since it was expected a negative coefficient for this variable. However, as switching to natural gas made unnecessary the use such equipment, the coefficient could be reflecting the existence of savings because sources could stop using such technologies after adoption.

Adoption Results and Contingencies: Hazard Rates with p Value in Parenthesis			
	Logit	Cloglog	Gamma
N° Of Shutdowns$_{t-1}$	1.005	1.005	1.012
	(0.504)	(0.457)	(0.357)
Residential Boilers	1.566	1.491	1.296
	(0.000)*	(0.000)*	(0.097)***
Bakery Ovens	0.295	0.293	0.111
	(0.000)*	(0.000)*	(0.000)*
Fuel Price	1.902	1.814	1.536
	(0.000)*	(0.000)*	(0.000)*
Permit	1.294	1.260	0.686
	(0.171)	(0.189)	(0.321)
FlowRate2	1.063	1.061	1.001
	(0.524)	(0.516)	(0.992)
FlowRate3	1.678	1.582	3.092
	(0.039)**	(0.048)**	(0.013)**
FlowRate4	2.629	2.393	3.923
	(0.000)*	(0.000)*	(0.003)*
Flowrate5	5.321	4.528	11.262
	(0.000)*	(0.000)*	(0.000)*
Previous Change	0.265	0.287	0.325
	(0.000)*	(0.000)*	(0.000)*
Equipment	1.479	1.447	2.923
	(0.267)	(0.254)	(0.007)*
Year 1999	1.166	1.139	0.874
	(0.209)	(0.250)	(0.472)
Year 2000	1.145	1.122	0.849
	(0.308)	(0.351)	(0.407)
Year 2001	1.116	1.104	0.406
	(0.422)	(0.437)	(0.000)*
Year 2002	0.628	0.638	0.419
	(0.001)*	(0.001)*	(0.000)*
Year 2003	0.298	0.308	0.037
	(0.000)*	(0.000)*	(0.000)*
Year 2004	0.199	0.208	0.074
	(0.000)*	(0.000)*	(0.000)*
Year 2005	0.0212	0.022	0.061
	(0.000)*	(0.000)*	(0.000)*
N	14724	14724	13290
Log Likelihood	-2604.94	-2606.67	-1038.75

* = significant at 1%.
** = significant at 5%.
*** = significant at 10%

Table N° 10: Adoption Results

Since the fixed effects seem to be so important, the logit specification was estimated by type of stationary source[13]. Table N° 11 displays the results, where most of the results remain the same. As it can be seen, there is an important role of the lower price of natural gas [$Fuel\Pr ice$] inducing adoption for all sources and of $\Pr eviousChange$ discouraging it. Regarding the effect of the size, this does not change in the case of industrial boilers and bakey ovens. For the first, all the size´s dummies [$FlowRate2$, $FlowRate3$, $FlowRate4$ and $FlowRate5$] are positive and statistically significant while for bakery, belonging to the group of the "biggest" sources [$FlowRate3$] increases the probability of adoption. Residential boilers seem to have adopted at the same rate, independently of the size, although the rate of adoption of those sources discharging emission at a flow rate between 1200 and 1900 $m^3/hour$ [$FlowRate3$] is lower at a 10% of significance.

An important difference among types of sources is the significance of the environmental regulation. While the effects of the tradable permit system remained insignificant for both types of boilers, the number of shutdowns is positive and significant in the case of industrial boilers, indicating that for this type of source the contingencies system did increase statistically the adoption probability.

The previous result suggests the existence of differences in the cost of being closed across sources, either due to differences in the cost of being closed or differences in the probability of being closed.[14]. With regards to the last point, in the analysis about the switching decision it is assumed that the probability of being closed during a bad quality episode is equal to one. But if sources are not forced to shutwdown, the economic incentives of the regulation disappear. The results seem to support such an idea, since the lack of effect of the contingencies system for some stationary sources appear to be strongly related to the lack of monitoring efforts. In fact, as it can be seen in Table N° 5, the probability of being inspected varied a lot across stationary sources and across years. While it was never lower than 70% for industrial sources, it decreases approximately to 20% for the rest, being residential boilers more prone to be inspected than bakery ovens. Unfortunately, data to test more carefully such a hypothesis it is not available.

Regarding the baseline, the results show a significant decrease in the rate for adoption from 2003 onwards for all groups, probably reflecting the natural gas crisis, and from 2000 for industrial boilers which can correspond to a vintage effect mentioned previously.

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[13]In spite of the fact that the Gamma specification seemed to have the best fit of the data, the logit specification was chosen since the algorithm behind the estimation procedure is simpler and less observations are dropped out.

[14]In a series of interviews, PROCEFF´s workers mentioned that residential boilers could avoid the cost of being closed moving the combustion process to the night previous to the start of the shutdown. So, even although residential boilers were very affected by contingencies, the benefits of avoiding shutdowns were not enough to be drive the adoption decision. Unfortunately, I do not have date to prove such a hypotesis.

Adoption Results and Contingencies: Hazard Rates with p Value in Parenthesis			
Variable	Industrial Boilers	Residential Boilers	Bakery Ovens
N° Of Shutdowns$_{t-1}$	1.035	0.997	1.000
	(0.045)**	(0.220)	(0.990)
Fuel Price$_t$	1.741	2.201	2.362
	(0.001)*	(0.000)*	(0.026)**
Permit	1.545	1.145	
	(0.119)	(0.624)	
FlowRate2$_t$	2.055	0.995	0.264
	(0.003)*	(0.966)	(0.191)
FlowRate3$_t$	3.571	0.380	10.294
	(0.001)*	(0.098)***	(0.050)**
FlowRate4$_t$	5.143	1.386	
	(0.000)*	(0.491)	
FlowRate5$_t$	9.963	1.058	
	(0.000)*	(0.944)	
Previous Change	0.351	0.176	0.086
	(0.000)*	(0.000)*	(0.001)*
Equipment$_t$	1.704	1.409	1.522
	(0.290)	(0.600)	(0.686)
Year 1999	0.858	1.562	0.923
	(0.444)	(0.008)*	(0.876)
Year 2000	0.443	2.048	0.936
	(0.002)*	(0.000)*	(0.902)
Year 2001	0.501	2.043	0.663
	(0.006)*	(0.000)*	(0.441)
Year 2002	0.282	1.095	0.252
	(0.000)*	(0.628)	(0.027)**
Year 2003	0.153	0.484	0.298
	(0.000)*	(0.006)*	(0.057)**
Year 2004	0.042	0.312	0.286
	(0.000)*	(0.000)*	(0.023)**
Year 2005	0.041	0.015	
	(0.000)*	(0.000)*	
N	3208	6771	3932
Log Likelihood	-636.47	-1672.63	-236.88

* = significant at 1%.
** = significant at 5%.
*** = significant at 10%

Tabla N ° 11: Adoption Results for Subsamples

To calculate the relative importance of the explanatory variables on the hazard, the approach from Snyder, Miller and Stavins (2003) is followed. It consists in calculating the hazard rate when all continuous variables are evaluated at their mean and the dummy variables are equal to zero. Then, the marginal effect of each dummy variable is obtained as the difference between the probability obtained when that variable takes a value equal to one and the "mean probability" of adoption. For continuos variables, the marginal effect is calculated as the impact on the mean hazard rate of increasing them by 10 percent. Table N° 12 shows the results for the entire sample while Table N° 13 shows the results for subsamples.

Change From Mean Hazard and Contingencies		
		Hazard Model
Mean Hazard		*8.25%*
Economic Variables	Flow Rate2	0.503%
	Flow Rate3	5.21%**
	Flow Rate4	12.01%*
	Flow Rate5	28.51%*
	Previous Change	-5.99%*
	Equipment	3.71%
	Residential Boilers	7.77%*
	Bakery Ovens	-5.01%*
	Fuel Price	1.12%*
Regulatory Variables	N° of Shutdowns	0.008%
	Permit	2.29%
Baseline	Year 1999	1.31%
	Year 2000	1.14%
	Year 2001	0.913%
	Year 2002	-2.98%*
	Year 2003	-5.71%*
	Year 2004	-6.55%*
	Year 2005	-8.07%*

* = significant at 1%
** = significant at 5%
*** = significant at 10%

Table N° 12: Effects of Covariates on the Mean Hazard Rate

From Table N ° 12 it follows that the mean probability of adoption is equal to 8.25%. Size increases this probability significantly. In fact, belonging to the biggest sources

[$FlowRate5$] increases this probability almost 29% while a 10% increase of the relative price rises it in 1.12%. Considering that the price of natural gas was almost half of the price of the rest of the clean fuels, this implies a total effect equal to 11.2%

Not having changed to a cleaner non natural gas fuel before decreases the probability of adoption almost 6%. On the other hand, the rate of adoption of residential boilers is 7.77% higher and the rate of adoption of bakery ovens is 3.71%.

These results remain basically the same for subsamples, although the impact of the fuel price is much more significant for industrial boilers, with a total effect of 17.8%. Regarding the impact of the contingencies system for this group, if the number of days of shutdown would increase from 1.95 to 2.95, which means approximately 50% of increase on the number of days that industrial boilers had to shut down, the probability of adoption would increase 1.45%.

Change From Mean Hazard and Contingencies				
		Industrial Boilers	*Residential Boilers*	*Bakery Ovens*
Mean Hazard		*8.25%*	*15.92%*	*3.14%*
Economic Variables	Flow Rate2	6.75%*	1.17%	-2.67%
	Flow Rate3	14.6%*	-4.70%***	25.44%**
	Flow Rate4	19.94%*	4.60%	
	Flow Rate5	40.56%*	0.15%	
	Previous Change	-4.45%*	-6.16%*	-8.63%*
	Equipment	3.16%	2.46%	2.39%
	Fuel Price	1.78%*	1.05%*	0.58%**
Regulatory Variables	N° of Shutdowns	0.29%**	-0.001%	0.000%
	Permit	2.97%	-0.005%	
Baseline	Year 1999	-0.86%	4.38%**	-0.7%
	Year 2000	-3.43%*	8.80%*	-1.11%
	Year 2001	-3.07%*	4.16%**	-1.92%
	Year 2002	-4.45%*	-1.30%	-2.83%**
	Year 2003	-5.28%*	-6.50%*	-2.81%**
	Year 2004	-5.99%*	-7.28%*	-2.50%**
	Year 2005	-6.00%*	-10.0%*	

* = significant at 1%.
** = significant at 5%.
*** = significant at 10%

Table N° 13: Effects of Covariates on the Mean Hazard Rate for Subsamples

¿Why did the tradable permit system did not encourage the switching to natural gas?

The absence of statistically significant impacts of the tradable permit system is a surprising result since previous studies conjetured that this policy was an important driver behind technological upgrades. The reasons behind its lack of effect can be found in the literature about the performance of the Santiago´s tradable permit system mentioned previously. In fact, Montero, Sánchez and Katz (2002), O´Ryan (2002) and Palacios and Chávez (2002) highlight its poor performance while Coria (2006) emphasizes that the quantity of emission rights available has exceeded the sources´s requirements since the beginning of the system for most sources. So, looking back at the analysis of the benefits of adoption for large boilers it is possible to conclude that the savings due to the lower use of emission rights were close to zero over the entire period analyzed. Then, there are no reasons to expect that the inclusion into this program increased the probability of adoption in global terms.

Refining the analysis, the hazard model was estimated for the subsample of sources that were not granted emission rights and that had to buy them. Table N° 14 shows the results for industrial and residential boilers. Even in this case the analysis suggests that there could be some role of the tradable emission permit encouraging adoption in this case, the empirical results do not show a statistically significant effect.

Adoption Results for Sources That Did Not Receive Emission Rights: Hazard Rates with p Value in Parenthesis		
Variable	Industrial Boilers	Residential Boilers
N° Of Shutdowns$_{t-1}$	1.027	0.987
	(0.178)	(0.212)
Fuel Price$_t$	2.337	2.166
	(0.000)*	(0.000)*
Permit	1.115	1.109
	(0.758)	(0.734)
FlowRate2$_t$	2.001	1.000
	(0.005)*	(0.999)
FlowRate3$_t$	5.510	0.431
	(0.000)*	(0.208)
FlowRate4$_t$	7.032	0.980
	(0.000)*	(0.972)
FlowRate5$_t$	14.111	1.417
	(0.000)*	(0.677)
Previous Change	0.348	0.158
	(0.000)*	(0.000)*
Equipment$_t$	2.03	1.592
	(0.034)**	(0.485)
Year 1999	1.231	1.581
	(0.392)	(0.007)*
Year 2000	0.760	2.021
	(0.369)	(0.000)*
Year 2001	0.784	1.991
	(0.432)	(0.000)*
Year 2002	0.477	1.088
	(0.028)**	(0.654)
Year 2003	0.293	0.487
	(0.008)*	(0.006)*
Year 2004	0.0335	0.316
	(0.001)*	(0.000)*
Year 2005	0.061	0.016
	(0.000)*	(0.000)*
N	2709	6698
Log Likelihood	-483.29	-1651.27

* = significant at 1%.
** = significant at 5%.
*** = significant at 10%

Table N° 14: Adoption Results for Sources That Did Not Receive Emission Rights

4.6 Conclusions

This paper analyzes the drivers behind the adoption of natural gas and its timing in Santiago, concluding that the stationary sources were more sensitive to the lower price of this fuel than to the environmental regulation. Surprisingly, the impacts of the environmental policies are scarce and limited just to industrial sources. Regarding this point, the results suggest that differences in the efforts that the environmental authority carried out to verify the regulation fulfillment can be very important explaining the output of the policies. This can be a key element explaining differences in the output of the environmental regulation between developed and emerging countries and further research is required to verify its impact.

With regards to the Santiago´s tradable permit system, it did not affect the adoption probability, which rises new questions about its performance and the economic incentives that it provides to adopt new technologies.

4.7 References

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4.8 Annexs

Annex N° 1

Table N° 15 details the chronogram of entrance of natural gas to the communes of Santiago.

Natural Gas Entrance to the Communes of Santiago	
1997	Cerrillos, Cerro Navia, Conchalí, Estación Central, Independencia, La Cisterna, Macul, Maipú, Ñuñoa, La Pintana, Pedro Aguirre Cerda, Pudahuel, Puente Alto, Quilicura, Quinta Normal, Recoleta, Renca, San Bernardo, San Joaquín, San Miguel, Santiago.
1998	Colina, Huechuraba, La Granja, La Reina, Lampa, Las Condes, Lo Espejo, Peñalolen, San Ramón
1999	Buin, Paine, Vitacura.
2000	Isla de Maipo, Malloco, Peñaflor, Providencia, Talagante
2002	Mostazal
2003	La Dehesa
2004	Graneros
Source: METROGAS	

Table N° 15: Natural Gas Entrance to the Communes of Santiago.

Annex N° 2

To make clear the non linear pricing scheme used by METROGAS I provide an example of it, detailing the variable and fixed charge´s structure used by METROGAS during 1999.

Variable Charge

The variable charge is a decreasing function of the level of monthly consumption. Table N° 16 describes the average fee depending on the quantity of natural gas used.

Structure of the Variable Charge in 1999		
Range of consumption (m^3 per month)	US$ per m^3	Average US$ per m^3
0-180	0.3688	0.3688
180-300	0.3504	0.3614
300-750	0.3135	0.3327
750-1500	0.1660	0.2493
1500-3000	0.1660	0.2076
3000-15000	0.1199	0.1376
15000-30000	0.1143	0.1280
30000-60000	0.1143	0.1221
60000-90000	0.1143	0.1202
90000-120000	0.1143	0.1191
120000-150000	0.1143	0.1184
150000-300000	0.1106	0.1154
300000-600000	0.1088	0.1132
600000-900000	0.1081	0.1121
900000-1200000	0.1070	0.1114
1200000-1500000	0.1070	0.1106
Source: METROGAS		

Table N° 16: Variable Charge

Thus, for example, a source using 1.500 cubic meters of natural gas per moth would pay an average fee equal to US$ 0.2493 per cubic meter, where the price of each cubic meter inside the first range of consumption is equal to US$ 0.3688, the price of each cubic meter inside the second range of consumption is equal to US$ 0.3504, the price of each cubic meter inside the third range of consumption is equal to US$ 0.3135 and the price of each cubic meter inside the last range is equal to US$ 0.1660.

Fixed Charge

The fixed charge depends also of the level of consumption. However, to calculate this fee METROGAS uses the consumption per hour.

Structure of the Fixed Charge in 1999	
Range of consumption (m^3 per hour)	US$ per month
0-33	30
33-108	70
108-280	150
280-699	250
699-1505	350
1505-1634	450
1634-5376	500
5376-10753	600
10753-21505	700
Source: METROGAS	

Table N° 17: Fixed Charge

Thus, a source using 280 cubic meters of natural gas per hour would have to pay monthly a fixed charge equal to US$ 250.

Chapter 5

Transactions in The Santiago Emission Market: ¿Why did sources lost their emissions rights?

5.1 Introduction

Policy makers have paid an increasing attention to market- based policy instruments over the last decade. Tradable emission permits have been at the center of this discussion due to the claims of their cost-effectiveness. The enthusiasm for this approach has been so great that policy action and implementation of such a system has advanced in countries like Chile, even without a complete understanding of how fundamental design issues should have been considered. This paper is an attempt to evaluate critically, after ten years of its launching, the compensation system for particulate matter applied in Santiago, describing the transactions that have taken place until now, the obstacles that the system has faced and how it has reacted to new regulations and market conditions.

With regard to the system, from its initial design it has faced several regulatory changes modifying its level of stringency. The total mass of emissions granted at the beginning has been decreased twice while the rate of offsetting has been risen twice. In spite these regulatory reductions in the supply of permits, many firms that had emission rights have lost them since to keep them, they must remain operative. If for some reasons any of these firms exits the market, it has a short period of time to exchange their permits before they become void. As a matter of fact, currently only a 56% of the initial mass of permits remains valid and almost 40% of the decrease in the quantity of emission rights can be explained by the absence of exchange in the allowed time period. ¿Why did firms did not trade their permits before they became void?. Clearly, there could be many reasons that explain this behavior. In this paper it is argued that design and implementation issues are responsible for the absence of exchange and the loss of emission rights.

Understanding the mistakes in the implementation of the compensation system seems very timely today since in 2007 a new group of sources will be included in the program. Originally, the program was focused just on large boilers, but at the beginning of 2007 industrial processes will be also included. Both kinds of sources will be assembled in the particulate matter´s emissions market while a new program to control nitrogen oxide emissions coming from industrial processes will be introduced. The expansion of the original program and the introduction of a new one will encourage the adverse effects of design and enforcement problems, so to analyze the actual performance of the system and to detect its weakness could help to improve it before that.

Previous work analyzing the performance of the Santiago´s compensation program was done at early stages of its implementation. Montero et al. (2002) found that the grandfathering used to allocate emissions initially created economic incentives for incumbent sources to more readily declare their historic emissions in order to claim any permits. They also pointed out that even though the market was not fully developed due to transaction costs, regulatory uncertainty and incomplete enforcement, the compensation program provided sources with the flexibility to adapt to new market conditions, like the natural gas availability. In the meantime, O´Ryan et al (2002) examined what was the impact of the introduction of natural gas in the applicability of the tradeable permit system, concluding that this clean fuel increased the range of emissions potentially abated at a lower cost and reduced the efficiency gains from using a market based instrument. On the other hand, Palacios and Chávez (2002)evaluate the performance of system in terms of the enforcement, concluding that an aggregate level of over-compliance coexists with usual violations to the regulation from some sources. In some sense, this paper extends the analysis carried out previously, but focusing on the effect of design issues not considered previously on the actual market transactions to date.

This paper is organized as follows. Next section presents a description of the compensation system applied in Santiago. The third section describes its evolution an its weakness. The fourth section reviews the lessons we can learn from this experience and the conclusions.

5.2 The Chilean Compensation System for Particulate Matter

In 1992, the Chilean environmental authority established a compensation system for particulate matter emissions trying to control the adverse effects produced for the excessive level of this pollutant in Santiago. Due to their easy identification and their relative importance, the system focused in large boilers, which at the date of implementation produced more than 40% of the total mass of particulate matter emissions. Although the system became mandatory in 1994, giving to the environmental authority two years to collect information on sources´s emissions, in practice it started working just in 1997.

Current environmental law regarding the compensation system rests mainly on two legal pieces: Supreme Decree 4 (promulgated in 1992) and Supreme Decree 16 (promulgated in 1998). I next synthesize the main regulatory elements contained in these legal pieces.

SD 4 established the basis of the system, defining as large boilers all boilers (either industrial boilers and ovens or large residential and commercial heaters) with emissions discharged through a duct or stack at a maximum flow rate $\geq$ 1000 m^3/hour. A cap for their emissions was established in 1997, together with a compensation system in which sources could offset their emissions with other large boilers. To implement the system, SD 4 distinguished between two kinds of large boilers: existing and new ones. Existing boilers were those installed or approved at the time SD 4 was promulgated while new boilers were those entering after that date.

Existing boilers were granted emission permits. On the other hand, new large boilers, were required to offset completely their emissions through the pollution abatement of existing sources.

The rate of offsetting was set up at 100%, but in 1998 SD 16 rose this rate to 120%. Additionally this Decree reduced the quantity of permits given initially to existing sources. In fact, SD 4 established that each existing large boiler would receive emission permits according to the following formula:

Daily Emissions (kg/day) = Flow Rate(m^3/hr)*56(ug/m^3)*24(hr/day).

As it was pointed out by Montero et al. (2002) since regulated sources were relatively small for the purpose of implementing sophisticated monitoring process, the program was not designed on the basis of actual sources´s emissions but rather on a proxy variable equal to the maximum emissions that a source could emit in a given period of time. The previous formula means then that each source was supposed to emit daily a maximum given by the product of emissions concentration (ug/m^3) times the maximum flow rate (m^3/hr) of the gas existing the stack. The first emission concentration target was set up at 56(ug/m^3), but in 1998 it was decreased to 50(ug/m^3) and all the emission permits given in excess of the new target were not recognized. SD 4 established also that at the beginning of 2000, the offsetting rate would be increased again up to 150% and that just the emission permits compatible with a new concentration target of 32(ug/m^3) would be kept in force.

Each year, the Point Sources Emission Control Program (PROCEFF) must verify if the number of permits held by each source coincides with the estimated emissions. If not, the source must trade permits to reach the estimated emissions. If the estimated emissions exceed the emission permits, the large boiler must buy emission permits. If the emission permits exceed the estimated emissions, the difference can be sold or retained. All trades require approval by the regulatory agency, either those trades among sources that share common ownership or those among non related sources. Additionally, sources are restricted to trade permits on either an annual or permanent basis.

Those sources that did not use their emission permits for a period longer than two year would loose their permits. At the same time, those sources that exit the market would have just three years to sell their permits before they became void.

SD 16 established also the need to include industrial processes into the compensation program, in such a way to induce a reduction in their emissions of particulate matter and nitrogen oxide[1]. For that, large processes were classified also between existing and new ones. Existing processes would be granted emission permits equal to the 50% and 67% of their actual level of emissions during 1997, respectively. New processes will have to offset 120% of their emissions of nitrogen oxide and 150% of their emissions of particulate matter. The deadline to comply with these new regulations was set up at May first of 2007. Preliminary estimations suggest that the number of industrial processes affected by these new policies is around 120 for particulate matter and 210 for nitrogen oxide. In each case, almost 67% of the sources correspond to existing ones.

5.3 The Evolution of the Chilean Compensation System

Table N°1 shows how the stock of emission permits has evolved from 1997 to 2005 while Table N°2 displays some statistics regarding the transactions carried out until now.

At the beginning of 1997, 4031.44 kilograms of particulate matter were allocated among 437 existing sources. Currently, just a 56% of the total mass of initial emission permits remains valid. 5.4% of it has been reduced due to the increase in the rate of offsetting while 21.6% has been eliminated due to the new concentration targets imposed by the regulatory authority. Additionally, more than 17% of the initial emission permits have been lost because existing sources did not exchange or used them before the legal deadline. In fact, 126 existing sources, almost a 30%, have lost emissions permits to date.

Emission Permits Evolution

	Total Kg per day	%
Total Emissions allocated at 1997	4031.44	100.0%
Emissions reduced due to the 1998 increase in the rate of offsetting (1.2)	123.67	3.1%
Emissions reduced due to the 2000 increase in the rate of offsetting (1.5)	75.52	1.9%
Emissions reduced due to the 2000 concentration target (50ug/m^3)	300.52	7.5%
Emissions reduced due to the 2005 concentration target (32 ug/m^3)	567.01	14.1%
Emissions lost due to non-trading	703.46	17.3%
Total Emission Permits in force at 2005	2261.27	56.1%

Source: Elaborated from data provided by PROCEFF

Table N° 1:Emission Permits Evolution

[1] This reduction objective for nitrogen oxide will be increased to 50% in 2010.

Total Trading Activity			
	# sources	# of transactions	Total Kg per day
Approved offsets	346	214	1417.37
Related Sources´s Offsets	279	140	924.42
Non Related Sources´s Offsets	67	74	492.95
Nº of sources that have traded more than once	80		
N° of Sellers	198		
Existing Sources	189		
New Sources	9		
N° Buyers	229		
Existing Sources	13		
New Sources	216		
N° of Sources That Lost Emission Permits Because They Did Not Trade		126	

Source: Elaborated from data provided by PROCEFF

Table N° 2: Trading Activity

So far, 214 transactions have been approved, involving 346 sources an a 35% of the total mass of initial emissions. A 65% of the total transactions corresponds to offsets among related sources while 35% are offsets among non related ones. Regarding the identity of buyers and sellers, we see, as it was predictable, that most buyers correspond to new sources entering the market after 1992 while most sellers correspond to existing sources. It is also interesting to notice that 25% of the sources offsetting emissions have traded more than once.

¿Why did many existing sources lost their emission permits? At least three answers can be given to this question. The first is the absence of a positive permit price since most sources relied on autarkic compliance. The second is the existence of substantial transaction costs in the particulate matter emissions market that discouraged sources to trade permits, and the third is the misunderstanding of the system that leads sources not to trade their permits before the legal deadline. Next, each one of these potential explanations is explored.

The Evolution of the Supply and Demand for Emission Rights Table N° 3 displays the supply and demand for emission permits from 1997 to 2005, where supply corresponds to the addition of all emission permits in force and demand corresponds to the addition of real emission from all large boilers.

Evolution of the Supply and Demand for Emission Permits (Kg/Day)			
Year	Emission Permits In Force	Real Emissions	Excess of Supply
1997	4031.44	2017.16	2014.28
1998	4031.44	1375.42	2656.02
1999	4031.44	711.41	3320.02
2000	3683.74	683.51	3000.23
2001	3651.77	535.79	3115.98
2002	3069.24	520.06	2549.18
2003	2950.52	563.17	2387.35
2004	2861.71	540.52	2321.19
2005	2261.27	613.43	1647.84
Source: Elaborated from data provided by PROCEFF			

Table N° 3: Evolution of the Supply and Demand for Emission Permits

As it can be seen from the Table, from the beginning of the system the quantity of emission permits has exceeded the requirements, producing a very significant excess of supply in spite of the regulatory reductions. Two factors can explain this fact: -an overestimation of the maximum emissions that a source could potentially emit daily and a fuel switching process that made the autarkic compliance a most feasible alternative. Table N° 4 separates the excess of supply into these two factors.

Regarding the first issue, the environmental authority granted emission permits assuming a 24 hour level of activity However, large boilers did not operate in average more than 18 hours by day, which produced an immediate excess of permits. Additionally, 128 sources that did not exist at 1997 received emission permits because they were operating at the time SD 4 was promulgated. Both elements give account of a 86.3% of the initial supply excess while the remaining excess can be explained by the fuel switching process that sources experimented starting from 1995, with the objective of meeting the environmental regulations. The relative importance of each element has changed through the time and the clean fuel conversion has become the main responsible.

About this conversion, natural gas was introduced in Santiago, through a gradual process of networks construction from 1997 to date, where most of the process was concentrated during 1997-1998. As of 2006, its introduction to the whole city is not finished yet, but it is available in most communes of Santiago. After its introduction, a quick adoption process started and currently almost 56 % of large sources use natural gas.

But natural gas was not the only clean fuel used by large sources. In fact, before 1997, many sources switched to other fuels as diesel N°2 or liquidified gas. Table N° 5 shows up the proportion of large sources using each kind of fuel. As it can be seen, the proportion of sources burning them has varied from 12.1% at the beginning of the sample to 95.1% at the end. There is not doubt that natural gas has been the preferred fuel, displacing diesel N° 2 because of its lower price. However, as a result of the Argentinean restrictions over the quantity of gas that can be imported from Chile we should expect that large sources will start to use mostly diesel N° 2 again.

All the mentioned fuels produce an emission concentration lower than 32 ug/m^3 which is the most demanding threshold imposed by the compensation system over the entire period, so clearly, the emission permits required by existing sources were minimized after adoption. But even through using clean fuels could help sources to reduce the permit requirements, transactions will not disappear since new sources have an imposed threshold equal to zero. In fact, 62% of all the trades correspond to new sources that bought permits.

Reasons Behind The Excess of Emission Permits

Year	Overestimation In The Level of Activity	Fuel Switching Process
1997	86.3%	13.7%
1998	58.2%	41.8%
1999	54.1%	45.9%
2000	53.4%	46.6%
2001	31.6%	68.4%
2002	27.9%	72.1%
2003	29.2%	70.8%
2004	31.1%	68.9%
2005	2.9%	97.1%

Source: Elaborated from data provided by PROCEFF

Table N°4: Reasons Behind The Excess of Emission Permits

Percentage of Large Boilers with Clean Fuels

Fuel	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Natural Gas	0.0%	0.0%	0.0%	13.1%	34.6%	41.5%	50.7%	56.4%	56.6%	58.3%	56.6%
Diesel N° 2	10.2%	20.9%	39.3%	50.8%	51.7%	47.5%	41.1%	34.0%	32.6%	30.0%	30.5%
Liquidified Gas	1.9%	3.6%	6.6%	6.9%	5.3%	5.8%	5.2%	5.3%	6.2%	6.0%	8.0%
Total	12.1%	24.4%	46.0%	70.8%	91.6%	94.8%	97.0%	95.7%	95.4%	94.3%	95.1%

Source: Elaborated from data provided by PROCEFF

Table N° 5: Percentage of Large Boilers Using Clean Fuels

Such an excess of supply implies a permit price equal to zero. Unfortunately, price information is not easy to obtain since sources do not have to inform to the environmental authority PROCEFF the price agreed for their transactions and because offsets among related sources do no have an explicit price. However information from occasional brokers suggests that prices have ranged from US$10.741(kg/day) in November of 1997, to US$ 5.555 (kg/day) in March of 1998 and from US$ 3704 (kg/day) in October of 2000 to US$ 2144 (kg/day) in 2005.

Montero et al. (2002) and O´Ryan(2002) analyzed the effects that the introduction of natural gas would have in the development of the particulate matter market. The first paper simulated a static "after natural gas" market estimating the annual aggregate marginal abatement cost curves for existing and new sources. They predicted that natural gas would induce an equilibrium price of zero while there would be no reduction requirements at the aggregate level. But still many offsetting would occur since new sources should cover their emissions with permits. On the other hand, O´Ryan focused in the effects that the availability of natural gas would have on the sources´s abatement costs under different environmental policies, concluding that under a tradable permit system the range of emissions reduced profitably increases the most.

Montero´s predictions seem quite accurate except that they missed the role of the initial emission permits endowment, that even without fuel conversion would have produced an excess of supply

Regarding the permits demanded by new sources, they were forced to buy permits as if they worked 24 hours, so many of them compensated much more than their actual activity requirements. Table N° 6 displays the evolution of the excess of emission permits in hands of the new large boilers. At the beginning of the period, these sources had less permits than their actual emissions. Precisely, the number of new sources that were not complying with compensations was not insignificant during the first years after the system implementation. As we will see in the next section this can be explained by the long time the transaction approval process lasts .However, as the fraction of sources that did not fulfill the regulation decreased, the excess of emission permits in hands of new sources increased a lot due to the activity assumption mentioned previously.

This evidence is consistent with the one found by Palacios and Chávez (2002). They review the monitoring aspects with respect to the compensation program and evaluate its performance in terms of enforcement , concluding that an aggregate level of over- reduction coexists with usual violations to the regulation from new sources[2].

[2] Palacios and Chávez (2002) report the number of sources that did not comply with their maximum level of emissions allowed for the period 1993-1999. Their estimations are lower than those exhibit in Table N° 6. The differences can be explained by the gaps between the date at which the compensations were requested from their approval date. In fact, the first compensation resolution date was just August, 28^{th} of 1998. In my estimations I consider that sources are reaching their environmental target when the transaction process is finished.

Evolution of the Supply Excess in Hands of the New Large Sources		
Year	Emission Permits Excess	N° of New Sources That Were Not Legally Compensating
1997	-334.61	93
1998	-165.60	99
1999	55.45	87
2000	318.80	98
2001	503.39	51
2002	608.39	36
2003	645.37	32
2004	773.15	23
2005	763.78	19

Source: Elaborated from data provided by PROCEFF

Table N°6: Emission Permits Excess in Hands of the New Large Sources

The Evolution of The Transaction Costs Transaction costs can be important on reducing trading probabilities of firms. For example, Gangadharan (2000) found that transaction costs were substantial in the initial years of the RECLAIM program, reducing the probability of trading by about 32% mostly explained by the absence of brokers and the high costs incurred when finding a trading partner and information costs of entering the market.

Before analyzing the transactions costs involved in the Chilean compensation system it is worth describing the stages of the compensation process. Specifically, sources trying to offset their emissions must fulfill the following steps:

- To request the offset and find a partner, either a source sharing common ownership or not.
- To sign an offsetting agreement specifying the emissions to be compensated and the sources involved in the transaction.

In the case of non related sources both steps must be legalized by a notary public.

- To certify the level of emissions of each source in the transaction through formal monitoring procedures.

After all this paperwork, PROCEFF can accept, reject the transaction or solicit additional information. If the compensation is accepted , a resolution grants the buyer with a quantity of daily emission allowed.

Search costs can potentially be rather high for the sources that do not have a related one. Then, we should expect that in the presence of high transaction costs related sources´s offsets would be much more common. This is the case since from 214 transaction to date, 65% correspond to auto- compensations and 35% to transactions among non related sources. In terms of the number of sources involved in the trading activity, almost a 81%[3] of them had a partner sharing ownership while 19% did not. However, besides suggesting the potential existence of important search costs, related offsets could be more common because sources used this mechanism as a way of avoiding a reduction in the number of emissions allowed. For example, transferring permits from one source to another, firms could avoid either the increase in the rate of offsetting or the reduction in the number of initial emission permits due to the decreased in the emissions ´s concentration target. With respect to the average quantity of emission permits traded, there are no differences among related and non related offsets.

Also, we should expect that if there are information costs of entering the market, which can be thought as a learning fixed cost, sources trade several times, since every time they trade they gain more experience and the learning cost go down. Transactions data seem to support the existence of such a cost, since as it was mentioned previously, almost 25%, of the sources offsetting pollution have traded more than once.

Regarding the administrative process to compensate emissions, even although it seems simple, in practice it takes a long period of time. Table N° 7 displays some statistics about this process.

[3] Such a percentage could even be higher since we are just considering as "auto-compensation" those offsets among sources belonging to the same firm. But in some cases different firms compensating could share ownership and this is not registered as an auto-compensation.

Transaction Process Period		
		Months
Total Offsets		
	Related Sources´s Offsets	21.3
	Non Related Sources´s Offsets	16.6
	Average	19.5
Offets Required Before 1998		
	Related Sources´s Offsets	39.3
	Non Related Sources´s Offsets	38.3
	Average	39.1
Offsets Required After 1998		
	Related Sources´s Offsets	17.2
	Non Related Sources´s Offsets	14.5
	Average	16.2

Source: Elaborated from data provided by PROCEFF

Table N° 7: Transaction Process Period

The average period required to conclude a transaction has been 19.5 months. However, there is an important difference in the transaction process period depending the year the compensation was applied for. In fact, all those transactions requested before 1998 took more than 3 years to be concluded while those later to that date took a little less than a year and a half. The reason behind this is the late implementation of the compensation system since as it was mentioned previously, whereas the system became mandatory in 1994 it started working only at the end of 1997. In that moment, the existing sources received their initial emission permits and the requested compensation were accomplished. As a matter of fact, the first compensation´s resolution dates from the middle of 1998.

Regarding the differences between related and non related offsets, surprisingly the first type took a longer period of time, which can be explained because the regulatory efforts were focused first on solve such a kind of offsets.

Then, the previous evidence suggests the existence of considerable transactions costs associated with trading in this market.

The Knowledge About The System ¿Did sources lost permits because they did not understand the system?. If this is true, this would be inconsistent with the rent seeking behavior suggested by Montero et al (2002) since they found that many sources that were not registered at 1992, when SD 4 was promulgated, but were eligible to receive permits had the incentives to report itself and claim its permits.[4] So, if sources made efforts to get emission rights, the absence of transaction should not be imputed to the poor understanding of the system.

To clarify this point the differences between those sources that loose permits and those that not are explore. If the poor understanding is important, small sources should be expected to loose permits most frequently since the benefits of acquiring information are lower. For the same reason, firms not having related sources should be expected to loose more.

Table N° 8 displays some statistics. Clearly, data does support such a hypothesis since there are clear differences in the sources´s level of activity and pollution. In fact, more than 60% of such sources had related partners to trade. while in 45% of the cases the partners were operating.

Description Sources Granted with EDI				
	Sources That Lost EDI		Sources That Did Not Loose EDI	
	N°	%	N°	%
	126	100%	311	100%
Not operating	81	63.3%	47	15.1%
Did Not Trade Ever	87	68.0%	118	37.9%
Had Related Sources	92	71.9%	256	82.3%
Has Related Sources in Operation	62	48.4%	230	74.0%
Daily Emissions	1.34 Kg/Day		3.21 Kg /Day	
Source: Elaborated from data provided by PROCEFF				

5.4 What Can We Learn From The Chilean Compensation System?

There is no doubt that despite of their advantages, tradable permit systems have been used far less frequently than command and control policies. But, according to Stavins (1998)

[4]In particular, they found that 85 sources approached the regulator claiming permits. From them, 72 received the status of existing sources and initial emission rights

the political process has gradually become more receptive to this policy instrument over the last decades. Regarding air pollution, in the 1970s, The Environmental Protection Agency (EPA) let USA´s states the option to use tradable permits to control localized air pollutants. In 1980, a tradable permit system was used in the phase down of leaded gasoline and on the phase down of ozone-depleting chlorofluorocarbons. But maybe the most famous application of this instrument corresponds to the sulfur dioxide (SO_2) allowance trading program intended to reduce a 50% of the nationwide emissions of this pollutant by the year 2000. The review of such experiences [see Stavins(1998), Tietemberg(2002) and Schmalensee et al.(1998)] offers normative lessons that point out the importance of taking into consideration issues like flexibility, simplicity, monitoring and enforcement and the provision of price information and matching partners.

The flexibility of a tradable permit system implies to allow for a broad set of compliance alternatives to be considered, in terms of timing and technological options. This means "banking" permits for future use. "Banking" seems have played a very important role in the SO_2 and lead performance´s programs since it accommodated the dynamic market changes that were occurring allowing shifts in the industry structure without affect the total emissions.

Regarding simplicity, there should be no requirements for prior government approval on individual trades. Stavins (1998) argues such requirements did hamper EPA´s Emissions Trading Program in the 1970. In the meantime, the lack of such requirements contributed to the success of the lead and SO_2 programs since this reduced the uncertainty for firms and administrative costs for government, decreasing the transaction costs.

The importance of monitoring and enforcement provisions have been also highlighted since if they are not considered, they do not provide enough incentives for a very high degree of compliance.

Finally, the inclusion of the private sector fulfilling brokerage needs seems to have been another important element in the SO_2 program implementation. Private firms have provided a variety of services, like private brokerage, electronic bid/ask bulletin boards and permits price forecasts.

¿How are these design recomendations incorporated into the Chilean compensation system?. The design of the Chilean system forgot all these issues. The system is not flexible, allowing just for transactions among sources included in the program that keep in operation. If they leave the market, they face a deadline to exchange their permits before they become invalid. There are requirements for prior government approval on individual trades, that .in practice lead the transaction process to take a long time. The incomplete enforcement besides the regulatory delay have allowed new sources to not fulfill the regulation for many years, and. finally, the existence of .private brokerage has been very limited as also the role of the environmental authority reducing searching costs.

In spite of all these weaknesses, the main reason behind the limited development of the market and the waste of emission permits has been the excess of emission permits in force. As I showed, the quantity of emission permits has almost doubled the real requirements from sources either because too many permits were granted initially or because new fuels have allowed sources to pollute less.

5.5 References

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Chapter 6

Conclusions

The analysis of the relation between policy instruments and technological adoption undertaken in this dissertation has yielded three key results. First, the model developed in Chapter 3 has demostrated that market based instruments not always work better than command and control policies inducing the adoption of a new technology. In a framework where the firm´s pre-adoption profit as well as its post-adoption profit may depend on the number of adopters, command and control instruments may produce the greatest welfare, even though emission taxes produce an earlier sequence of adoption. The crux of the difference between an emission tax and a tradable permit system is the price endogeneity. As soon as a firm adopts the new technology, the market price of the permit decreases while the tax remains unchanged. This price reduction reduces the profitability of the additional abatement, making the savings on the abatement costs lower. However, it encourages all firms in the industry to increase their level of production, improving the consumer´s welfare. Taking into account both flows of benefits, a tradable permit system must be preferred over a tax. In the meantime, the crux of the difference between an emission standard and a tradable permit system is the fraction of profits because the decrease in the cost of production that the adopter can retain. The use of the tradable permit system equates the cost of production of adopters and non adopters in the margin, so this fraction is lower in this case.

The theoretical prediction that market based instruments grant firms with more incentives to adopt new technologies is tested empirically in Chapter 4. Using data about the switching to natural gas in Santiago it has been demonstrated that stationary sources were more sensitive to changes in the cost of the energy than to the costs of the environmental regulation. This finding gives rise to the second key result. The monitoring and enforcement efforts carried out by the environmental authority to verify the fulfillment of the regulation differs across firms, and the differences seem quite correlated with the output of the regulation. In fact, the only group for which the contingencies system, an apparently very demanding command and control policy, had some impact was the group in which the monitoring efforts were focused. So, this suggest that the lack of significant impacts of the environmental policy could be explained by the lack of a proper enforcement that compels sources to pay the costs of the regulation. This issue can be particularly relevant in emerging countries, where budgets restrictions makes enforcement less probable.

Finally, the lack of effect of the compensation system implemented in Santiago suggests how important can be the design and implementation of a policy if policymakers really wants it to promotes more environmentally friendly decisions.