Environment for Development

Discussion Paper Series

October 2008 ■ EfD DP 08-28

Environmental Policy, Fuel Prices, and the Switch to Natural Gas in Santiago, Chile

Jessica Coria

Environment for Development

RESOURCES FOR THE FUTURE

Environment for Development

The **Environment for Development** (EfD) initiative is an environmental economics program focused on international research collaboration, policy advice, and academic training. It supports centers in Central America, China, Ethiopia, Kenya, South Africa, and Tanzania, in partnership with the Environmental Economics Unit at the University of Gothenburg in Sweden and Resources for the Future in Washington, DC. Financial support for the program is provided by the Swedish International Development Cooperation Agency (Sida). Read more about the program at www.efdinitiative.org or contact info@efdinitiative.org.

Central America
Environment for Development Program for Central America
Centro Agronómico Tropical de Investigacíon y Ensenanza (CATIE)
Email: centralamerica@efdinitiative.org

China
Environmental Economics Program in China (EEPC)
Peking University
Email: EEPC@pku.edu.cn

Ethiopia
Environmental Economics Policy Forum for Ethiopia (EEPFE)
Ethiopian Development Research Institute (EDRI/AAU)
Email: ethiopia@efdinitiative.org

Kenya
Environment for Development Kenya
Kenya Institute for Public Policy Research and Analysis (KIPPRA)
Nairobi University
Email: kenya@efdinitiative.org

South Africa
Environmental Policy Research Unit (EPRU)
University of Cape Town
Email: southafrica@efdinitiative.org

Tanzania
Environment for Development Tanzania
University of Dar es Salaam
Email: tanzania@efdinitiative.org

Environmental Policy, Fuel Prices, and the Switch to Natural Gas in Santiago, Chile

Jessica Coria

Abstract

In this study, I analyze the role of environmental policies and energy cost savings in the switch to natural gas by stationary sources in Chile. According to the data, most of the switching was induced by the lower cost of natural gas, although environmental policies played a small role and showed that sources were more sensitive to the cost of energy than to environmental regulation.

Key Words: Environmental policy, technological adoption, tradable permits, developing countries

JEL Classification: O29, O32, O38, Q55, Q58

Contents

Environmental Policy, Fuel Prices, and the Switch to Natural Gas in Santiago, Chile

Jessica Coria*

Introduction

In many large cities in developing countries, increased population and economic development have brought with them increased levels of air pollution. Facing the growing problem of deteriorated air quality, policy makers have to decide what kind of regulatory instruments to use. The successful experience with economic instruments in some developed countries has led many analysts to propose the use of these policies in the developing world. While some analysts are skeptical about the use of market-based policies in the developing world, others have focused their attention on specific policies, discussing the advantages and disadvantages of various economic instruments.

Market advocates argue that this approach allows developing countries to more readily accommodate economic growth while decentralizing decision making for control options, providing greater incentives for technological change and lowering overall compliance costs. "Market skeptics" emphasize that developing countries lack of the experience, institutions, and resources necessary to design and operate economic instruments effectively (see Bell and Russell 2002; Bell 2004). Some market advocates argue that design deficiencies and pervasive constraints on monitoring and enforcement can affect the performance of both economic policies, command, and command and control policies, although the implementation of more sophisticated policy instruments, such as tradable emission permits, would require major institutional changes. Emissions fees might then more appropriate since they can provide foundation for a transition to an effective economic incentive system and raise revenue for environmental projects and programs (see Eskeland et al. 1992; Krupnick 1997; Blackman and

* Jessica Coria, Gotherburg University (and Universidad Diego Portales) Department of Economics, P.O. Box 640, SE 405 30 Gothenburg, Sweden; (email) jessica.coria@economics.gu.se; (tel) + 46-31-7864867.

This work was carried out with the aid of a grant from the Latin Ameican and Caribbean Environmental Economics Program (LACEEP). I am grateful to José Miguel Sanchez, Juan Pablo Montero, Rodrigo Cerda, Allen Blackman, Suzi Kerr, Gert Wagner, Rodrigo Tronsoco, Gonzalo Edwards, and participants at LACEEP meetings for their helpful comments. I would also like to thank the generous people at PROCEFF (particularly Marta Zamudio and Roberto Condori) and Ian Nelson (METROGAS) for the data used in this paper.

Harrington 2000). Finally, those in favor of trading approaches argue that, as countries develop and economies and political systems become more willing to impose real environmental requirements, trading programs will become more adequate. Then, the important point is to start developing the institutions now that will build over the coming years (see Krueger 2003).

However, in spite of the extensive ongoing debate about these issues, experience with environmental policies is not very large or deep, and there is little empirical evidence about the performance of environmental regulations in less developed countries. This paper is an attempt to contribute to this discussion and disentangle the role of environmental regulations and market forces behind a major air quality improvement in Santiago, Chile.

Santiago is one of the most polluted cities in Latin America. During the early 1990s, it was officially declared a non-attainment zone for several atmospheric pollutants. However, during the late 1990s, there was major improvement due to a switch to natural gas by stationary sources. The switch allowed stationary sources to reduce particulate matter emissions, the pollutant which produces the worst health effects, by about 67 percent. The process of switching coincided with major new policy initiatives designed to improve air quality, including both command and control and market-based policies. But, it also coincided with the increased availability and reduced price of natural gas.

What was responsible for the switch to natural gas in Santiago—environmental regulations, market forces, or both? In this study, I used a panel data set of stationary sources to identify the impact of environmental policies on energy cost savings and its inducement to switch to cleaner gas as fuel.

The extent to which the environmental policy successfully improved the air quality in Santiago is policy relevant. It allows us to understand how regulations can provide incentives to make environmentally friendly decisions in less developed countries, to learn how regulators can engineer this feat, and be sensitive to the constraints they face in the process. It also helps us understand whether regulations can trigger technological innovations than can be profitable to firms and benefit the environment.

Since the effect of environmental policies on the development and spread of new technologies is among the most important determinants of success of environmental protection efforts in the long run, analyzing the link between the choice of policy instruments and technological change has been the subject of considerable theoretical work. However, there has been exceptionally little empirical analysis. Most studies focus on the effects of alternative policy instruments on the innovation of energy-efficiency technologies because data have been more available. Greene (1990), for example, tested the effectiveness of CAFE[1] standards and gasoline prices in new-car fuel economy, concluding that both were significant, although CAFE standards were much more influential on gasoline prices. On the other hand, Newell et al. (1999) analyzed the effects of increasing energy prices and raising government standards on the energy efficiency of air conditioners and gas water heaters, finding that both energy prices and government standards affected the energy efficiency.

Kerr and Newell (2000) assessed the effects of the tradable permit program implemented to phase out lead in gasoline in the United States during the 1980s. They found that the tradable permit program provided incentives for more efficient technology-adoption decisions, as evidenced by a significant divergence in the adoption behavior of refineries with low versus high compliance costs. In other words, the positive differential in the adoption propensity of expected permit sellers (low adoption-cost refineries) relative to expected permit buyers (high adoption-cost refineries) was significantly greater under tradable permits, compared to individually binding performance standards.

In line with this result, Keohane (2001) found that the sulfur dioxide allowance trading program initiated under the U.S. Clean Air Act Amendments of 1990 also provided incentives for more efficient technology-adoption decisions. In particular, he found that the choice of whether or not to adopt a "scrubber" to remove sulfur dioxide, rather than purchasing more costly low-sulfur coal, was more sensitive to cost differences under the tradable permit than under the earlier emission standards.

Previous studies analyzing the performance of the Chilean tradable permit program include Montero et al. (2002), O'Ryan (2002), Palacios et al. (2005), and Coria and Sterner (2008). Montero et al. (2002) highlighted the role of the grandfathered allocation which encouraged incumbent sources to more readily declare their emissions. O'Ryan (2002) emphasized the role of natural gas in decreasing the cost of emission abatement and reducing the efficiency gains from using a tradable permit program. Palacios et al. (2005) reviewed monitoring and enforcement, concluding that noncompliance by some sources coexists with an aggregated level of over-compliance. Finally, Coria and Sterner (2008) looked closely at the program's performance over the past 10 years, stressing its discrepancies with successful trading

[1] CAFE standards were created in 1978 with the purpose of reducing energy consumption by increasing the fuel efficiency of cars.

programs implemented in developed countries and analyzing how it has reacted to regulatory adjustments and market shocks.

What can we learn from Santiago's experience? Basically, that when it is time to undertake technological change, firms are quite responsive to changes in relative prices. Thereby, there is room for environmental policies in less developed countries to modify relative prices for the sake of promoting environmental targets. However, the institutional context is actually a key element explaining differences in the output of environmental regulations between developed and emerging countries and, as argued by marked advocates, these constraints affect the performance of both market-based and command and control policies.

1. Chilean Environmental Regulation

During the early 1990s, 20 percent of total emissions of particulate matter (PM_{10}) in Santiago came from stationary sources. Industrial boilers and industrial processes were the largest emitters (47 percent and 46 percent**,** respectively)**,** with a small contribution coming from residential boilers and bakery ovens (6 percent and 1 percent, respectively). Three major environmental policies were implemented to control their emissions: a cap and trade program, a concentration standard, and a contingency program.

The cap and trade program was implemented in 1992 by Supreme Decree 4 (SD 4), although it started in practice in 1997. It affected emissions coming from large boilers (both industrial and residential), which discharged emissions through a duct or stack with a maximum flow rate higher than 1000 m^3/hour.

SD 4 established an individual cap on the emissions of large boilers and a tradable permit program that allowed them to exceed this cap through offsetting their emissions with other, less polluting large boilers. For the purpose of granting permits, it differentiated between existing and new large boilers. Existing boilers were those installed or approved before 1992 and were granted emission permits. New large boilers were required to offset their emissions fully through the emissions abatement of existing large boilers.

Initially, the daily cap on emissions of existing large boilers was calculated according to a formula that allowed them to emit a maximum derived from a target on emissions concentration equal to 56(ug/m^3) times the maximum flow rate (m^3/hr) of the gas in the stack times 24 hours of operation:

$$\text{Daily Emissions (kg/day)} = \text{Flow Rate } (m^3/hr) * 56(ug/m^3) * 24(\text{hours/day}) \qquad (1)$$

However, as the program continued, the environmental authority realized that its initial allocation was too generous. They modified the quantity of allowable emissions for existing large boilers by decreasing the target on emission concentration to 50(ug/m^3) in 2000 and to 32(ug/m^3) in 2005. The offsetting rate was also modified. Initially, it was set at 100 percent. In 1998 it was increased to 120 percent, and in 2000 it was increased to 150 percent.

For the rest of the stationary sources, SD 4 established a standard for allowable emissions concentration equal to 56ug / m^3, which was reduced to 32ug / m^3 in 2005.

Table 1 summarizes some statistics about the tradable permit program from 1997 to 2005. The summary contains information about the number of sources in the program, the initial allocation of permits, aggregate emissions, aggregate permits in force, and the offsetting of permits.

Table 1 Tradable Permit Program

Variable	1997	1998	1999	2000	2001	2002	2003	2004	2005
Number of sources	593	583	516	534	495	513	521	526	519
Existing sources	430	402	332	324	286	277	273	264	251
New sources	163	181	184	210	209	236	248	262	268
Permits in force (kg/day)	4045.40	4044.40	4054.56	3710.37	3680.43	3087.34	2944.86	2856.05	2315.87
Initial daily emissions (IDE)	4045.40	3963.36	3672.76	3195.08	2981.53	2162.52	1897.75	1746.98	1123.49
Daily permitted emissions (DPE)	0	81.04	381.80	515.29	698.90	924.82	1047.11	1109.07	1192.38
Aggregate emissions (kg/day)	2544.79	1804.60	865.75	824.55	650.21	603.59	649.76	624.33	688.51
Existing sources	1684.27	1214.04	622.29	599.92	465.75	439.43	404.40	445.87	498.61
New sources	860.52	590.56	243.46	224.63	184.46	164.16	245.37	178.46	189.91
Excess of Permits [(a)]	1500.60	2239.80	3188.80	2885.81	3030.22	2483.75	2295.10	2231.72	1627.35
Existing sources	2361.13	2749.32	3050.47	2595.15	2515.78	1723.08	1493.36	1301.11	624.88
New sources	-860.52	-509.52	138.34	290.66	514.44	760.66	801.74	930.61	1002.47

Source: Elaborated from PROCEFF databases

(a) Excess of permits corresponds to the difference between the permits in force and the aggregate emissions

At the beginning of 1997, 4045.40 kilograms of emitted particulate matter were allocated among 430 existing sources. Currently, only 53.7 percent of the initial mass of permits remains in force and 60 percent is in the hands of new large boilers. Notice that although the aggregate cap on emissions was accomplished from the beginning, new sources did not offset their emissions during the first years of the program. Montero et al. (2002) argued that one of the reasons behind this outcome was the lack of institutional capability to regulate stationary sources. Before permits could be allocated, it was necessary to develop a comprehensive inventory of sources and their historical emissions. Because of limited resources, the regulator concentrated its regulatory activity on the completion of the inventory and the allocation of permits. As consequence, the regulator did not track trading activity until the process was completed, so there was no reconciliation of permits and emissions until the market began to take off at the end of 1998.

The daily cap on emissions implicit in the equation (1) weight far overestimated real emissions from existing large boilers, producing an excess of permits in force since the beginning of the program that has been intensified because of the switch to cleaner fuels. According to Coria and Sterner (2008), this excess number of permits in force has prevented the market from fully developing, in the sense that many sources rely on autarkic compliance instead of participating in the permits market.

Supreme Decree 32 (1990) implemented a contingency program to control emissions from all stationary sources, during declared states of "environmental contingencies" of bad air quality. These episodes occur when an environmental quality index reaches high values.[2] If the index reaches a value over 300, a "pre-emergency" episode is declared. If it reaches a value over 500, an "emergency" episode is declared. Every year, the environmental authority prepares the contingency lists. Sources on the pre-emergency list must shut down during a "pre-emergency" episode, while sources on in the emergency list must shut down during an "emergency" episode.

To construct the lists, sources are ordered according to their PM_{10}-emission concentration. The source with the highest PM_{10} concentration is at the top of the list, and the source with the lowest PM_{10} concentration is at the bottom. From 1998 to 2000, those sources exhibiting the higher PM_{10} concentration—and held responsible for 30 percent of the total mass emissions—were included in the pre-emergency list while those held responsible for 50 percent of the total mass of emissions were included in the emergency list. In 2001 the regulation was redefined in terms of absolute pollution. The authorities established a new threshold of 32 and 28

[2] The environmental authority measures the levels of PM_{10} per hour in a set of monitoring stations. The measuring is used to construct the environmental quality index ICAP that varies between 0 and 500.

ug/m³ of PM_{10}-emission concentration to shut down the sources during pre-emergencies and emergencies, respectively.

Table 2 shows some information about critical episodes and the number of sources included in the lists. As critical episodes have not been rare, sources have tried to avoid being included in the contingency lists. However, the criterion used until 2000 implied that, because some sources took steps to reduce pollution, it became increasingly difficult for the rest to avoid being included. Therefore, the number of sources in the lists increased as the concentration threshold decreased abruptly. The criterion was modified in 2001 and the number of sources in the pre-emergency list started to decrease, while the number of sources in the emergency list stayed the same for the most part.

Table 2 Contingency Program

Sources in the Contingencies Lists									
Year	*1997*	*1998*	*1999*	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*
Sources in the Pre-Emergency List									
Days in Pre-Emergency	*13*	*12*	*14*	*11*	*4*	*11*	*5*	*2*	*2*
Number of Sources in the List	*141*	*230*	*1007*	*1176*	*521*	*336*	*359*	*178*	*155*
Pre-Emergency Concentration Threshold (ug/m3)	92.9	77	35.4	30.1	32	32	32	32	32
Industrial Boilers	63.83%	47.39%	18.77%	19.64%	17.85%	21.43%	14.76%	8.99%	11.61%
Residential Boilers	16.31%	26.09%	54.42%	62.50%	58.73%	53.87%	42.34%	5.06%	3.23%
Bakery Ovens	0.00%	4.78%	12.91%	4.85%	4.22%	8.04%	7.24%	0.00%	0.00%
Industrial Processes	19.86%	21.74%	13.90%	13.01%	19.19%	16.67%	35.65%	85.96%	85.16%
Sources in the Emergency List									
Days in Emergency	*0*	*1*	*1*	*0*	*0*	*0*	*0*	*0*	*0*
Number of Sources in the List	421	887	2619	2483	1657	1472	1574	1584	1635
Emergency Concentration Threshold (ug/m3)	63	50	28.9	22	28	28	28	28	28
Industrial Boilers	57.24%	33.26%	15.43%	15.67%	12.55%	12.23%	10.80%	9.53%	12.42%
Residential Boilers	12.83%	39.57%	54.98%	45.63%	44.00%	38.25%	33.48%	29.29%	28.56%
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%

Source: Elaborated from data provided by PROCEFF

The relative importance of stationary sources within the lists changed from 1998 to 2005. During 1997 and 1998, industrial boilers became the most affected group. Residential boilers became the most affected group after that, until 2003. On the other hand, bakery ovens have not been very affected by pre-emergencies, although their share on the emergency list has increased since 1999. Finally, the relative importance of industrial processes increased from 2004 onwards.

Given the fiscal and technical resources constraints, monitoring and enforcement activities were mostly focused on industrial boilers because of their relative importance in total emissions. During the last decade, industrial boilers were much more prone to be inspected than residential boilers and bakery ovens, as displayed in table 3. Although the number of sources inspected has increased over time, just a small fraction of residential boilers and bakery ovens was actually inspected from 2000 to 2003.[3]

Table 3 Proportion of Stationary Sources Inspected by Group

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

2. Natural Gas Adoption, Environmental Policy, and Fuel Prices

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. Natural gas was introduced through a gradually constructed network, heavily concentrated, between 1997 and 1998. Even its introduction to the whole city is yet not completed, although it is available in the most communes of Santiago.

There are clear differences within the pattern of switching followed by stationary sources. Table 4 shows the switching rate by boilers (distinguishing between the overall rate of switching by industrial and residential boilers and the rate of switching by large boilers within each group) and bakery ovens from 1998 to 2005. Unfortunately, there is no identification variable that allows observing industrial processes through time. Henceforth, industrial processes are excluded from the analysis.

[3] Unfortunately, PROCEFF does not have records on inspection activities for the entire period or source-level data.

Table 4 Rate of Switching to Natural Gas

	Industrial Boilers				Residential Boilers					
	Overall		Large Boilers		Overall		Large Boilers		Bakery Ovens	
Year	N	Switching Rate	N	Switching Rate	N	Switching Rate	N	Switching Rate	N	Switching Rate
1998	612	4.7%	504	9.9%	1018	0.0%	79	9.9%	505	0.2%
1999	620	18.8%	442	25.4%	1225	1.7%	74	30.5%	613	0.7%
2000	660	24.7%	449	30.1%	1706	20.6%	85	37.5%	660	1.7%
2001	643	33.4%	414	42.3%	1809	41.8%	81	50.3%	860	5.7%
2002	644	39.6%	433	47.6%	1916	53.8%	80	59.0%	945	7.4%
2003	641	41.3%	446	52.0%	2011	57.7%	75	62.9%	1031	8.2%
2004	624	45.0%	451	56.1%	2109	61.7%	75	66.5%	1127	10.1%
2005	636	42.6%	445	52.8%	2890	58.8%	74	69.2%	1168	12.5%

Source: Elaborated from data provided by PROCEFF and METROGAS

Industrial boilers started to switch to natural gas earlier, while residential boilers began to switch heavily after 2000. Since then, the rate of switching of residential boilers has increased quickly, exceeding industrial boilers at the end of the period. Within each group, large boilers switched earlier and the rate of switching slightly exceeded the overall rate at the end of the period. On the other hand, just 12.5 percent of the bakery ovens switched to natural gas and the rate of switching is very flat along the period.

At a first sight, both environmental policies seem quite correlated with the switching process. First, large boilers started switching earlier, suggesting some facet of the tradable permit program encouraged this process. Second, the lag of the relative importance of stationary sources in the pre-emergency list is clearly correlated with their pattern of switching. The switching rate of industrial boilers took off between 1998 and 1999, after they became the group most affected by this policy. The same happened with residential boilers, which started to switch heavily in 2000, while bakery ovens which were not very affected did not switch very much. However, since natural gas was the cheapest clean fuel available, there is also room for relative fuel prices being the main driver explaining the switching. In fact, in most cases, switching to natural gas reduced production costs because of the lower cost per unit of energy. Additionally, since natural-gas supplier METROGAS used a non-linear pricing scheme to offer volume discounts, switching was more profitable to large sources using more fuel. Table 5 shows some statistics about the relative fuel expenditure in 1998 for a sample of industrial boilers, residential boilers, and bakery ovens, and for a sample of fuels used previously for most stationary sources.

Table 5 Fuel Expenditure and the Switching

Fuel Expenditure and the Switching					
			Relative Fuel Expenditure in 1998		
Previous Fuel	PM10 Concentration	N° of Sources that switched	Industrial Boilers	Residential Boilers	Bakery Ovens
Diesel N° 5	78*	20	0.69	0.60	0.60
Diesel N° 2	30	958	2.19	1.92	1.91
Kerosene	30	16	1.90	1.66	1.66
Liquidified Gas	15	99	2.32	2.03	2.03
City Gas	15	70	3.01	2.64	2.63
New Users**	15	1391	1.00	1.00	1.00
N		2554			

Source: Elaborated from data provided by PROCEFF and METROGAS

* Estimated from a sample of sources using Diesel N° 5 in 1998

** New users that started operations burning natural gas

For each previous fuel, the relative expenditure was calculated as the ratio between the expenditure in energy in 1998, using that fuel and the expenditure if it were burning natural gas.

Even though the fuel expenditure using diesel #5 was lower, this fuel did not allow sources to meet the environmental regulation because of the high level of PM_{10} concentration it produced. Therefore, after its introduction, natural gas became the cheapest clean fuel available. The switching implied significant reductions in the fuel expenditure for most sources, although industrial boilers were the sources who benefited the most.

Next section introduces the methodology used to disentangle the role of environmental regulations and fuel prices driving the switching to natural gas.

3. Methodology

According to the Chilean environmental law, large boilers—producing an average level of output X^i_t higher than a threshold $\overline{X}$ — must compensate their emissions, trading permits at a price p_t. Non-large boilers—producing an average level of output lower than a threshold $\overline{X}$ — must meet a concentration standard $\overline{\delta_t}$. Finally, both large boilers and non-large boilers emitting more than a concentration threshold $\overline{\alpha_t}$ were included in the contingency program and forced to shutdown during critical episodes that occurred with probability μ_t.

Switching to natural gas not only helped sources decrease their level of emission but also offered several other benefits to sources. First, the lower level of emissions produced with this fuel, e_t^{NG}, allowed large boilers to reduce the number of emission permits used, e_t^i. Second, it allowed non-large boilers to reach the concentration standard since their emissions concentration was lower than the threshold $\overline{\delta_t}$ at any time. Third, it allowed all sources to leave the contingency program at any time their emissions concentration was lower than the threshold $\overline{\alpha_t}$. Finally, it reduced the cost of required energy due to the differences in the market prices of gas.

Let z_t^{NG} be the market price of the natural gas, z_t be the vector of prices of the remaining fuels, r be the intertemporal discount rate, and W^{NG} be the investment required to acquire the capital input necessary to burn natural gas. Let the variable *PERMIT* denote if the source was included in the trading program (taking a value equal to 1 for large boilers and zero otherwise) and d_t to indicate if the source was included in the contingency program at the time t or not (taking a value equal to 1 if it was included and zero otherwise). Let the variable s_t indicate whether a non-large boiler reached the concentration standard at time t or not (taking a value equal to 1 if it did not reach the standard and zero otherwise). Finally, let us assume that for a representative source the cost of being closed at the time t corresponds to L_t, while the cost of not reaching the concentration standard is F_t.

Sources will switch to natural gas when the cost of delaying the switch equals the benefit.

If, since each source is a profit maximizer, it chooses the date of adoption to fulfill the following, then, the following arbitrage condition must hold:

$$permit * p_t * (e_t^i - e_t^{NG}) + (1 - permit) * s_t * F_t + \mu_t * d_t * L_t + X_t^i (z_t^i - z_t^{NG}) = r * W^{NG} \tag{2}$$

Thus, large boilers would switch to natural gas insofar as the expected benefit from avoiding the shutdown, plus any gain in the energy expenditure, plus any saving due to the reduction in the use of emission permits compensate the opportunity cost of the required investment. In the meantime, non-large boilers would switch insofar as the expected benefit from avoiding a shutdown and the standard concentration plus the gains in the energy expenditure compensate the opportunity cost.

A hazard model was indented to estimate how the variation of environmental regulations and fuel prices modified the decision to switch. For each firm, the hazard function is defined as the probability of switching to natural gas at time t, given that it has not switched yet. Formally:

$$h(t,x_t,\beta)=\frac{f(t,x_t,\beta)}{1-F(t,x_t,\beta)}\ , \qquad (3)$$

where the behavior of the hazard function depends on the distributional assumptions for the cumulative distribution function $F(t,x_t,\beta)$ and probability density $f(t,x_t,\beta)$, as along the way the set of explanatory variables x_t changes over time. The parameters β can be estimated using maximum likelihood.

In spite of the switch occurring in continuous time, spell lengths are observed only at intervals of a year. Unfortunately, the experiment is not long enough to assume a continuous approximation.[4] Thus, the two leading discrete distributions 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 $z(t) = c(t)+\beta' x_t$ be the hazard rate for a representative source in year *t*. Then, the shapes of the logistic and complementary log-log time hazard functions correspond to:

$$\begin{aligned} h^{Logistic}(t,x_t,\beta) &= [1+\exp(-z(t))]^{-1} \\ h^{CLog-Log}(t,x_t,\beta) &= 1-\exp[\exp(z(t))] \end{aligned} \qquad (4)$$

In both models, all differences between sources are assumed to be captured through the covariates. Regarding the choice of shape of the duration dependence specification *c(t)*, 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 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 restrictions over the quantity of gas that can be imported from Argentina since 2004.

The dependent variable $NATURALGAS_t$ indicates whether a source is using natural gas at each point in time within sample or not, having a value equal to 1 if the source is using natural

[4] Kerr and Newell (2001) used data on 378 refineries over 25 years. Data used in this paper covers just over eight years, since natural gas only became available in 1998.

gas at the time *t* and zero otherwise. The next two sections cover the covariates used to explain $NATURALGAS_t$.

3.1 Independent Variables

To capture the impact of environmental policies, the following variables are included:

PERMIT: This is a dummy variable that takes a value of 1 if the source is regulated through the tradable permit system and zero otherwise. Since large boilers could reduce the use of emission permits by switching, this coefficient is expected to be positive and statistically significant.[5]

NUMBER OF SHUTDOWNSt-1: To capture the impacts of critical episodes, the variable $NUMBER\ OF\ SHUTDOWNS_{t-1}$ was included. It equals the number of days that the sources included on either in the pre-emergency or emergency list, or both, had to close during the previous year due to these regulations:

$$NUMBER\ OF\ SHUTDOWNS_{t-1} = PRE\text{-}EMERGENCY_{t-1} * NUMBER\ OF\ PRE\text{-}EMERGENCIES_{t-1} + EMERGENCY_{t-1} * NUMBER\ OF\ EMERGENCIES_{t-1} \quad (5)$$

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.[6] More shutdowns increase the economic benefits from switching. Therefore, this coefficient is expected to be positive and statistically significant.

The variables *PERMIT* and $NUMBER\ OF\ SHUTDOWNS_{t-1}$ should pick up any effect that the tradable permit system and the contingency program had beyond the concentration standard.

FUEL EXPENDITURE GAP-t: Switching fuels affects production costs since each fuel entails a different per unit energy cost, either because of differences in fuel price or in the quantity required to generate the same level of production. In addition, METROGAS combines

[5] To give account of the impacts of the tradable permit system, the variable $DELTAEMISSONS_t$ was also intended. It corresponds to the difference between the emissions produced by the fuel in use and the emissions produced by natural gas. However, the estimation results of the hazard model using such a variable did not change.

[6] The variables PRE-$EMERGENCY_{t-1}$ and $EMERGENCY_{t-1}$ were also intended. $PRE\text{-}EMERGENCY_{t-1}$ was a dummy variable equal to 1 if the source was included in the pre-emergency list the previous year and zero otherwise. $EMERGENCY_{t-1}$ was a dummy variable equal to 1 if the source was included in the pre-emergency list the previous year and zero otherwise. The estimation results of the hazard model using such variables did not change. But $NUMBER\ OF\ SHUTDOWNS_{t-1}$ was preferred, since it was more meaningful in terms of the economic decision.

an average per cubic meter fee that decreases with volume with a fixed charge that increases with it. All these dimensions need to be included in the construction of a meaningful variable able to determine whether or not the cost advantages can explain the pattern of switching. Then, a relative expenditure variable was constructed, by source per year, considering the fuel the source was previously using. For any source previously using the fuel *i*, the relative expenditure 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:

$$FuelExpenditureGap_t^i = \frac{EnergyExpenditure_t^i}{EnergyExpenditure_t^{NG}} = \frac{z_t^i * X_t^i}{z_t^{NG}(X_t^{NG}) * X_t^{NG} + FixedCh\arg e_t(X_t^{NG})}, \qquad (6)$$

where X^i cubic meters of fuel *i* and X^{NG} cubic meters are required to produce the same output. 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 $FixedCh\arg e_t(X_t^{NG})$.[7] Due to data limitations, the analysis focused on those sources previously using diesel #5, diesel #2, liquidified gas, kerosene, and city gas. $FuelExpenditureGap_t$ is expected to be positive and statistically significant.

3.2 Control Variables

SIZE: Bigger sources should switch faster due to the existence of scale economies. The variable $FLOWRATE_t$ is a proxy, since it is strongly correlated with the size of the combustion process. It is defined as the rate at which emissions are discharged through a duct or stack. However, it is also strongly correlated with the type of policy instrument, since those sources which discharge their emissions at a rate higher than 1000 m^3/hour are regulated through the tradable permit program. To disentangle the effect of size from the regulatory effect, five $FLOWRATE_t$ dummy variables were created to reduce the correlation between both variables. The dummies are defined as follows: $FLOWRATE1_t$ takes a value equal to 1 if the source discharged its emissions at a rate lower than 500 m^3/hour and zero otherwise; $FLOWRATE2_t$ takes a value equal to 1 if the source discharged its emissions at a rate of 500–1200 m^3/hour and

[7] In the data set, energy consumption is expressed in kilograms by hour. The consumption by month by source was determined by multiplying the original variable times the number of hours a source works everyday and times the number of days that it works every month. Then, it was transformed into square meters (m^3) of fuel divided by the density of each fuel. After that, the physical consumption was expressed in money and the relative price was calculated.

zero otherwise; $FLOWRATE3_t$ takes a value equal to 1 if the rate varies between 1200 and 1900 m^3/hour and zero otherwise; $FLOWRATE4_t$ takes a value equal to 1 if the rate varies between 1900 and 3500 m^3/hour and zero otherwise. Finally, $FLOWRATE5_t$ takes a value of 1 if the rate is higher than 3500 m^3/hour and zero otherwise. All these coefficients are expected to be positive and statistically significant.

PREVIOUS CHANGE: Those sources burning cleaner fuels face fewer regulatory restrictions than those using dirtier fuels. In addition, there could be opportunity costs created by the previous switch. Then, if a source switched to cleaner non-natural gas fuels at some point in the sample, it could be less prone to switching again since the benefit will be lower and the capital cost will be higher. The dummy variable *PREVIOUS CHANGE* takes account of this effect. It takes a value equal to 1 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 expected 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.

BAKERY OVENS EFFECT: The main reason to include this variable is to capture the role of the Association of Bakery Owners, INDUPAN, which encouraged its members to switch to light oil. At the beginning of the 1990s, INDUPAN started to promote switching from wood to diesel #2. To support this, INDUPAN signed agreements with suppliers of the technology required to burn light oil and with a light oil company (Shell), offering discounted prices to its members. These measures were not offered again to promote the switch to natural gas. Thus, this coefficient is expected to be negative and statistically significant.

3.3 Data

Data employed was recorded by the Point Sources Emission Control Program (PROCEFF) and includes information from more than 5,000 sources from industrial boilers, residential boilers, and bakery ovens over 11 years (1995–2005).

The standard procedure to estimate discrete hazard models required re-organizing the data set so that for each source there were as many rows as there were intervals at risk of the event occurring for each source. Then, the panel was turned from one row of data per source to another in which each source contributed T_i rows, where T_i is the number of years *i* was at risk of switching. T_i is denoted as $STUDY\ TIME_i$. For a source that switched to natural gas, $STUDY\ TIME_i$ corresponds to the time until the switch. If a source never switched, it corresponds to the time the source survived in the experiment. However, it cannot be expected that sources switch to natural gas if this fuel was not available. Thus, the number of years at risk of sources switching, that were located in communes where natural gas was available after 1998, starts to be considered from the date at which natural gas entered that commune.[8]

Table 6 presents summary statistics of the covariates for the whole sample and table 7 presents summary statistics for industrial boilers, residential boilers, bakery ovens, and sub-samples of sources that switched and did not switch to natural gas.

As it can be seen in table 6, the tradable system program seems strongly correlated with the switching of industrial boilers, but it is not correlated with the switching of residential boilers. In any sub-sample, there is a positive correlation between the lag of the number of shutdowns and the switch, and between the fuel expenditure gap and the switch.

---

[8] Consider the case of a source that existed in 1998, but only had gas available in 2000 and switched to gas in 2003. For this source, then, STUDY $TIME_t$ equals 3.

Table 6 Summary Statistics

Variable	N° Obs.	Mean	Std. Dev.	Min	Max
NG_t	19618	0.105	0.307	0	1
Permit	19618	0.117	0.321	0	1
N° of $Shutdowns_{t-1}$	15284	1.964	4.321	0	15
Fuel Expenditure Gap_t	16966	1.918	0.468	0.5	3.6
$FlowRate^1_t$	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
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
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 7 Summary Statistics by Sub Samples

Variable	Industrial Boilers		Residencial Boilers		Bakery Ovens	
	Switched	Did Not Switch	Switched	Did Not Switch	Switched	Did Not Switch
	Mean		Mean		Mean	
NG_t	0.0687		0.184		0.0260	
Permit	0.608	0.316	0.046	0.073		
N° of $Shutdowns_{t-1}$	1.950	1.899	3.400	2.558	1.282	0.700
Fuel Expenditure Gap_t	2.140	2.012	1.954	1.830	2.041	1.906
$FlowRate^1_t$	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

4. Results

Table 8 displays the results under the complementary log-log specification. However, the results are robust to various distributional assumptions. The results reported are not the estimated values of the coefficients, but rather the exponentiated coefficients. 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.

Table 8 Switching Results

Switching Results		
Variable	*Hazard Rates with p Value in Parenthesis*	*Marginal Effects*
Permit	1.15 (0.43)	1.38%
N° of Shutdowns$_{t-1}$	1.09 (0.29)	0.15%
Fuel Expenditure Gap$_t$	**1.77 (0.00)***	**2.59%***
FlowRate^2_t	1.01 (0.91)	0.99%
FlowRate^3_t	1.43 (0.12)	3.96%
FlowRate^4_t	**2.12 (0.00)***	**9.85%***
FlowRate^5_t	**3.96 (0.00)***	**23.8%***
Previous Change	**0.27 (0.00)***	**-7.06%***
Equipment$_t$	1.47 (0.23)	4.32%
Bakery Ovens	**0.21 (0.00)***	**-7.65%***
Year 1999	1.14 (0.25)	1.28%
Year 2000	1.12 (0.34)	1.16%
Year 2001	1.10 (0.47)	0.91%
Year 2002	**0.64 (0.00)***	**-3.38%***
Year 2003	**0.31 (0.00)***	**-6.67%***
Year 2004	**0.21 (0.00)***	**-7.67%***
Year 2005	**0.02 (0.00)***	**-9.59***
Mean Probability of Switching		9.82%
N	14724	
Log Likelihood	-2616.31	

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

The marginal effects are also reported. The mean probability of switching is equal to 9.82 percent, and it is obtained 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 1 and the mean probability of switching. For continuous variables, the marginal effect is calculated as the impact on the mean probability of increasing them by 10 percent.

PERMIT and *NUMBER OF* $SHUTDOWNS_{t-1}$ have the expected signs, although surprisingly, none affects the likelihood of switching statistically. On the opposite, *FUEL EXPENDITURE* GAP_t is positive and statistically significant, suggesting the existence of important cost advantages of switching to natural gas.

The estimations show that the bigger sources ($FLOWRATE3_t$, $FLOWRATE4_t$ *and* $FLOWRATE5_t$) were more likely to switch to natural gas. On the contrary, to have switched to another cleaner non-natural gas fuel (*PREVIOUS CHANGE*) decreases the probability of change. In the meantime, to have abatement equipment (*EQUIPMENT*) at one's disposal affects the switching probability positively but not significantly.

The results are consistent with a significant fixed effect that indicates that being a bakery oven decreases the probability of switching. This suggest that regardless of the rest of the variables considered in the analysis, bakery ovens switched less, probably because of the incentives granted by INDUPAN.

The results also indicate that from 2002 onwards the stationary sources began to switch at a lower rate. One possible explanation for this is that the dummies captured some sort of vintage effect. Since the sources that did not switch (probably since they did not see enough benefits from the switch) are those that remained in the sample longer, the negative coefficients show that each year the adoption was 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 Argentine government on the quantity of gas that could be imported by Chile. Clearly, the crisis reduced the incentives to switch, given the uncertainty about its availability.

Regarding the marginal effects of the statistically significant variables, a 10-percent increase of the fuel expenditure raised the mean probability by 2.59 percent. Considering that the price of natural gas was almost half the price of all other clean fuels, this implied a total effect equal to 25.9 percent. Not having changed to a cleaner non-natural gas fuel before decreased the mean probability by almost 7 percent, while being a bakery oven reduced the mean probability by 7.65 percent. Size also affected the mean probability significantly. In fact, belonging to the biggest sources (*$FLOWRATE5_t$*) increased this probability almost 24 percent. Finally, from 2002 on, the mean probability of switching started to decrease significantly.

The model was also estimated by sub-samples of industrial boilers, residential boilers, and bakery ovens. Table 9 displays the results. Although most of them remain the same, an important difference is the significance of the environmental regulation. While the effects of the tradable permit program remained insignificant for both types of boilers, the contingency program did statistically increase the switching probability of industrial boilers. However, the marginal effect is very small. A 10-percent increase in the number of days that an industrial boiler had to shutdown the previous year increased the mean probability of switching by just 0.36 percent

In spite of its magnitude, the previous result suggests the existence of differences in the impact of the number of shutdowns, either due to differences in the cost of being closed or differences in the probability of being closed.[9] 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 1. However, if sources are not forced to shutdown, the economic incentives of the regulation disappear. The results seem to support such an idea. The lack of effect of the contingency program for some stationary sources appears to be strongly related to the lack of monitoring efforts. In fact, as it can be seen in table 3, the probability of being inspected varied a lot across stationary sources and across years. While it was never lower than 70 percent for industrial sources, it decreased approximately to 20 percent for the rest, given that residential boilers were more prone to be inspected than bakery ovens. Unfortunately, data to test such a hypothesis more carefully it is not available.

Again, there is an important role played by the lower price of natural gas to encourage the switch. Its impact is much more significant for industrial boilers, as it increased the mean probability by 38.5 percent, instead of 21.3 percent and 5.4 percent for residential boilers and bakery ovens, respectively.

[9] In a series of interviews, PROCEFF's workers mentioned that residential boilers could avoid the cost of the shutdowns by moving the combustion process to the night previous to the start of the shutdown. So, even though residential boilers were significantly affected by contingencies, the benefits of avoiding shutdowns were not enough to drive the decision to switch. Unfortunately, I do not have data to prove such a hypothesis.

Table 9 Switching Results for Sub Samples

Switching Results By Sub samples of Stationary Sources

Variable	*Industrial Boilers*		*Residential Boilers*		*Bakery Ovens*	
	Hazard Rates and P Value	Marginal Effect	Hazard Rates and P Value	Marginal Effect	Hazard Rates and P Value	Marginal Effect
Permit	1.512 (0.11)	2.91%	1.13 (0.65)	0.92%		
N° of Shutdowns$_{t-1}$	1.03 (0.03)**	0.36%	0.99 (0.24)	-0.02%	1.00 (0.99)	0.00%
Fuel Expenditure Gap$_t$	1.66 (0.00)*	3.85%	2.07 (0.00)*	2.13%	2.33 (0.03)*	0.54%
FlowRate^2_t	2.005 (0.00)*	5.60%	1.00 (0.97)	0.03%	0.27 (0.20)	-2.27%
FlowRate^3_t	3.27 (0.00)*	12.18%	0.40 (0.11)	-4.49%	9.41 (0.03)*	22.69%
FlowRate^4_t	4.49 (0.00)*	18.1%	1.35 (0.49)	2.52%		
FlowRate^5_t	8.38 (0.00)*	34.11%	1.01 (0.12)	0.71%		
Previous Change	0.392 (0.00)*	-3.55%	0.189 (0.00)*	-6.14%	0.09 (0.00)*	-2.84%
Equipment$_t$	1.56 (0.29)	3.15%	1.40 (0.55)	2.86%	1.50 (0.70)	1.52%
Year 1999	0.85 (0.35)	-0.87%	1.51 (0.01)***	3.64%	0.91 (0.84)	-0.29%
Year 2000	0.47 (0.00)*	-3.11%	1.95 (0.00)*	6.69%	0.92 (0.87)	-0.25%
Year 2001	0.54 (0.00)*	-2.69%	1.94 (0.00)*	6.60%	0.66 (0.42)	-10.65%
Year 2002	0.31 (0.00)*	-4.06%	1.08 (0.67)	0.57%	0.25 (0.03)*	-2.32%
Year 2003	0.17 (0.00)*	-4.90%	0.49 (0.01)*	-3.85%	0.30 (0.05)**	-2.18%
Year 2004	0.05 (0.00)*	-5.63%	0.32 (0.00)*	-5.12%	0.29 (0.02)*	-2.22%
Year 2005	0.05 (0.00)*	-5.90%	0.02 (0.00)*	-7.60%		
Mean probability of switching	5.91%		7.64%		3.12%	
N	3208		6771		3932	
Log Likelihood	-636.67		-1673.3		-236.85	

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

The effect of size is also more important for industrial boilers. Belonging to the group of the biggest industrial boilers ($FLOWRATE5_t$) increased the switching probability by 34.11 percent. In the meantime, belonging to the group of the biggest bakery ovens ($FLOWRATE3_t$) increased the switching probability by 22.69 percent. Residential boilers seem to have switched at the same rate, regardless of size.

The effect of a previous switch is higher for residential boilers, accounting for a 6.14-percent decrease in the probability of switching. Finally, the results by sub-samples show a significant decrease in the switching rate of all sources from 2003 on, probably reflecting the natural gas crisis, and from 2000 on for industrial boilers, which may be related to the vintage effect suggested previously.

However, the question remains: why did the tradable permit system not encourage the switching to natural gas? According to the previous results, the tradable permit program did not affect the probability of switching to natural gas. However, as it is quite difficult to disentangle the impacts of the tradable permit program from the size, I looked for another way to identify the effect of tradable permit program. For that, the hazard model was estimated for the sub-sample of sources that had to fully offset their emissions. These sources corresponded to new large boilers that began operations after Supreme Decree 4 was enacted and did not receive emission permits. Consequently, they needed to fully offset their emissions buying emission permits from the existing large boilers. Since the variable *PERMIT* captures the benefits of reducing the use of emission permits, this coefficient is expected to be positive and statistically significant when only the sub sample of new large boilers is considered.

Table 10 shows the results, differentiating between industrial and residential boilers. As can be seen even in this case, the results remain the same, showing that there was not a statistically significant effect of the tradable permit program speeding up the switch to natural gas and that the main driver of the switch was the lower price of natural gas.

Why did the tradable permit system not encourage the switching to natural gas? The reasons behind its lack of effect seem correlated with the implementation of the program. As was mention in section 3, since the environmental authority lacked good historical records on emissions by large boilers, they employed an allocation strategy that overestimated real emissions. Therefore, from the beginning of the program, emission permits in force have doubled the sources' requirements, producing a very significant excess of supply in spite of regulatory changes that have reduced the stock. The aggregate excess of supply must have produced a very low permit price of equilibrium, making the benefits from reducing the use of emission permits

Table 10 Switching Results for the Sub Sample of Large Boilers that Had to Fully Offset Their Emissions

Switching Results For The Subsample Of Large Boilers That Had To Fully Offset Their Emissions
(Hazard Rates With P Value In Parenthesis)

Variable	Industrial Boilers	Residential Boilers
Permit	1.12	1.11
	(0.76)	(0.73)
N° Of Shutdowns$_{t-1}$	1.03	0.99
	(0.18)	(0.21)
Fuel Price$_t$	**2.34**	**2.17**
	(0.00)*	**(0.00)***
FlowRate2$_t$	**2.00**	1.00
	(0.01)*	(0.99)
FlowRate3$_t$	**5.51**	0.43
	(0.00)*	(0.21)
FlowRate4$_t$	**7.03**	0.98
	(0.00)*	(0.97)
FlowRate5$_t$	**14.11**	1.42
	(0.00)*	(0.68)
Previous Change	**0.35**	**0.16**
	(0.00)*	**(0.00)***
Equipment$_t$	**2.03**	1.59
	(0.03)**	(0.49)
Year 1999	1.23	**1.58**
	(0.39)	**(0.01)***
Year 2000	0.76	**2.02**
	(0.37)	**(0.00)***
Year 2001	0.78	**1.99**
	(0.43)	**(0.00)***
Year 2002	**0.48**	1.09
	(0.03)**	(0.65)
Year 2003	**0.29**	**0.49**
	(0.01)*	**(0.00)***
Year 2004	**0.03**	**0.32**
	(0.00)*	**(0.00)***
Year 2005	**0.06**	**0.02**
	(0.00)*	**(0.00)***
N	2709	6698
Log Likelihood	-483.29	-1651.27

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

insignificant when compared to the savings from fuel consumption. Unfortunately, there is no information about permit prices to verify this hypothesis more carefully.

An additional explanation is provided by Palacios and Chávez (2005). According to the authors, the enforcement design used has not been able to induce high compliance levels because of a combination of monetary penalties that are not clearly defined and actual sanctions that are not automatically implemented but are decided on a case-by-case basis. As a consequence, the program has experienced individual violations from the beginning, particularly by new large boilers, and it has failed to provide enough incentives for firms to assume a high degree of compliance.

5. Conclusions

There is a growing interest in the use of economic instruments to address environmental problems in developing countries. However, some authors have expressed skepticism based on the lack of experience and lack of institutions necessary to design and operate such policies. These constraints would prevent these instruments from being cost effective, creating doubts about the extent to which developing countries should eschew or give up command and control policies instead of relying on economic instruments.

Regarding the use of different economic instruments, there is some agreement about the difficulty of easily replicating the successful experience of the United States with permit trading programs in developing countries. Instead, some authors have advised the use of emission fees. Since emission fees are politically feasible and provide valuable revenues to finance regulatory activity, they appear to be a more realistic and appropriate policy alternative.

This paper contributes to this discussion by producing new evidence of the role of environmental regulations and market forces in a successful air-quality improvement program in a less developed country. The main finding is that the institutional context is actually a key element explaining environmental regulation’s outcomes. In the case under analysis, switching to natural gas was basically a response to changes in relative fuel prices, instead of the consequence of various environmental regulations involving both command and control and market-based policies.

Why did the environmental regulation not work? There are many reasons to explain the poor performance of environmental policies: the lack of reliable baseline data and the deficiencies in monitoring and enforcement and the design of the environmental policies.

With regard to the lack of baseline data, the inventory of sources and emissions that PROCEFF had at the moment of implementation and distribution of permits was far from complete. As consequence, the program was not designed on the basis of sources' actual emissions but on a proxy variable equal to the maximum emissions that a source could potentially emit in a given period of time and that far overestimated actual emissions. Grandfathering the permits prompted rent-seeking behavior that also increased the permits in force, since it created incentives for false reporting by sources which were not operating at the time the program was implemented—although it allowed the regulator to more readily identify sources that are not in the original inventory (Montero et al. 2002, 273). The excess of permits in force has prevented the market from fully developing, in the sense that many sources rely on autarkic compliance instead of participating in the permits market.

In the Chilean environmental policy, monetary penalties are not clearly defined and actual sanctions are decided on a case-by-case basis. They might include a note of violation, as well as widely variable lump-sum monetary sanctions and quite infrequent prohibition of a sources' operation. As a consequence, monitoring and enforcement did not provide enough incentives for high degrees of compliance because of the legal inability to deal with them, once detected, and to set clear and effective sanctions.

The performance of environmental policies seems also quite correlated with the technical ability to detect violations. Santiago's program relies on self-reporting by regulated sources with monitoring conducted once a year. Daily emissions are approximated as the product of emissions concentration (in mg/m^3) times the maximum flow rate (in m^3/hour) of the gas exiting sources' stack times 24 hours of operation. By using this simpler monitoring procedure, the monitoring task was reduced to the measurement of few parameters, such as the source's size and fuel type. However, the large number of stationary sources involved in environmental policies demands that considerable resources be devoted to this activity. Because of resources constraints, environmental authority has focused monitoring and enforcement efforts on the main emitters. As consequence, the results of this study show a small but positive impact of the contingencies program explaining the switching by this group.

In spite of the small response by firms to environmental regulations, the large response to changes in relative prices suggests that there is room for the use of these policies, if institutional changes are implemented. In fact, the lower price of natural gas worked in practice as an environmental fee increasing the cost of using less clean fuels. The results show that it was very effective speeding up the switching process and improving the environmental quality. Why was it so effective? Because, different from environmental policies, it provided certain and considerable incentives for firms to take advantage of new market conditions.

References

Bell, R.G. 2004. "Choosing Environmental Policy Instruments in the Real World." Greenhouse Gas Emissions Trading and Project-Based Mechanisms. Paris: OECD.

Bell, R.G., and C. Russell. 2002. "Environmental Policy for Developing Countries," *Issues in Science and Technology* (Spring 2002). http://findarticles.com/p/articles/mi_qa3622/is_200204/ai_n9021332

Bento, A., M. Crooper, and A. Takeuchi. 2005. "The Impact of Policies to Control Motor Vehicle Emissions in Mumbai, India." Washington, DC: World Bank.

Blackman, A., and W. Harrington. 2000. "The Use of Economic Incentives in Developing Countries: Lessons from International Experience with Industrial Air Pollution," *Journal of Environment Development* 9: 5–44.

Coria, J., and T. Sterner. 2008. "Air Pollution and Tradable Permits in Developing Countries: How Have They Performed in Santiago, Chile?" Working Paper. Environmental Economics Unit, Gothenburg University, Sweden.

Coria, J. 2006. "Essays on the Effects of Environmental Policy on Technological Adoption." PhD diss. Pontificia Universidad Católica de Chile, Santiago.

David, L. 2008. "The Effect of Driving Restrictions nn Air Quality in Mexico City," *Journal of Political Economy* 116(1): 38–81. http://www-personal.umich.edu/~lwdavis/df.pdf

Eskeland, G., and E. Jimenez. 1992. "Policy Instruments for Pollution Control in Developing Countries," *World Bank Research Observer* 7(2): 675–740.

Greene, D. 1978. "Cafe or Price? An Analysis of the Effects of Federal Fuel Economy Regulations and Gasoline Price on New Car MPG, 1978–1989," *The Energy Journal* 11(3).

Jaffre, A., R. Newell, and R. Stavins. 2002. "Environmental Policy and Technological Change," *Journal of Environmental and Resource Economics* 22: 41–69.

Jenkins, S.P. 2005. "Survival Analysis." Unpublished manuscript. Institute for Social and Economic Research, University of Essex, Colchester, U.K.

Keohane, N.O. 2001. "Essays in the Economics of Environmental Policy." PhD diss. Harvard University.

Kerr, S., and R.G. Newell. 2001. "Policy-Induced Technology Adoption: Evidence from the U.S. Lead Phasedown," Resources for the Future Discussion Paper 01-14. Washington, DC: RFF. http://www.rff.org/Publications/Pages/PublicationDetails.aspx?PublicationID=17171

Kiefer, N. 1988. "Economic Duration Data and Hazard Functions," *Journal of Economic Literature* 26: 646–79.

Krueger, J., K. Grover, and J. Schreifels. 2003. "Building Institutions to Address Air Pollution in Developing Countries: The Cap and Trade Approach." Paper presented at the "OECD Global Forum on Sustaintable Development: Emissions Trading," Paris, March 17–18, 2003. http://www.oecd.org/document/38/0,3343,en_2649_34361_2507110_1_1_1_1,00.html

Krupnick, A. J. 1997. "Air Pollution in Developing Countries." In *Environment and Emerging Development Issues*, vol. 2, edited by P. Dasgupta and K.-G. Mäler. Oxford: Clarendon Press.

Montero, J.P., J.M. Sánchez, and R. Katz. 2002. "A Market-Based Environmental Experiment in Chile," *Journal of Law and Economics* 45: 267–87.

Neliseen, D., and T. Requate. 2004. "Pollution-Reducing and Resource-Saving Technological Progress." Economics Working Paper, no. 2004-07. Christian-Albrechts-Universität, Kiel, Germany.

Newell, R., A. Jaffre, R. Stavins. 1999. "The Induced Innovation Hypothesis and Energy-Saving Technological Change," *Quarterly Journal of Economics* 114(3): 941–75. http://www.nicholas.duke.edu/people/faculty/newell/RFFbookch05-newell.pdf

O´Ryan, R. 2002. "Emissions Trading in Santiago: Why Has It Not Worked, But Been Successful?" Unpublished manuscript. Program for Environmental Economics and Management, Industrial Engineering Department, Universidad de Chile.

Palacios, M., and C. Chávez. 2005. "Determinants of Compliance in the Emissions Compensation Program in Santiago, Chile," *Environment and Development Economics* 10: 453 –83.

Rose, N., and P. Joskow. 1990. "The Diffusion of New Technologies: Evidence from the Electric Utility Industry," *RAND Journal of Economics* .21: 354–73.

Snyder, M., L. Miller, and R. Stavins. 2003. "The Effects of Environmental Regulation on Technology Diffusion: The Case of Chlorine Manufacturing." Resources for the Future Discussion Paper, 03-25. Washington, DC: RFF. http://www.rff.org/documents/RFF-DP-03-25.pdf