Nº 192
Mayo 2000

Documento de Trabajo
ISSN (edición impresa) **0716-7334**
ISSN (edición electrónica) **0717-7593**

A Market-Based Environmental Policy Experiment in Chile.

Juan Pablo Montero
José Miguel Sánchez
Ricardo Katz

www.economia.puc.cl

ABSTRACT

Despite the increasing interest in the use of emissions trading for pollution control, empirical evidence reduces to a few experiences in the US. This paper studies the "emission-offsets trading program" established since 1992 to control particulate in Santiago-Chile. While the program is doing well from an environmental perspective, thanks, in part, to the price-based introduction of natural gas, the market is poorly performing because of high transaction costs, uncertainty and low enforcement. However, the scarcity rents created by the allocation of grandfathered emission rights to incumbents have proved very effective for the completion of the emissions inventory.

INDICE

1. INTRODUCTION

In recent years there has been a widespread interest in the use market-based instruments—particularly emissions trading or tradeable permits systems—to deal with air pollution problems, rather than the more traditional command-and-control approach of emission and technology standards. While almost all the experience with the use of tradeable permits systems is confined to the U.S. (Tietenberg, 1985; Hahn, 1989; Schmalensee et al. 1998), there are a few less developed countries (LDCs) that are beginning to experiment in different forms with emissions trading (World Bank, 1997). Close examination of these experiences comes at a particularly interesting time, since a global emissions trading system with some type of voluntary participation from LDCs is at the center of current negotiations that deal with climate change by curbing emissions of carbon dioxide and other greenhouse gases (Jacoby et al., 1999).

The purpose of this paper is to provide an evaluation of the "emission-offsets trading program" established by Supreme Decree No. 4 (DS 4) in March of 1992 to control total suspended particulate emissions (TSP) from stationary (industrial) sources in Santiago, Chile (hereafter, the Offset Program). In so doing, we describe the system and its creation from an institutional standpoint. We evaluate its environmental and market performance based on data from 1993 through 1999, and then suggest ways in which the functioning of this market might be improved, if possible, within the current institutional context.

The Offset Program was established to resolve, in a cost-effective manner, the conflict between industrial growth and progress towards meeting the ambient air quality standards for TSP and breathable particulate matter (PM10) in the city of Santiago, which have been constantly exceeded since the 70s. Under the Offset Program, *existing* sources—registered at the time the DS 4 was promulgated—received "emission-rights" proportional to a predetermined emissions rate level uniform across existing sources[1,2].

---

[1] Note that in our context, the term emissions rate refers to emissions concentration. The rate used to calculate the rights allocation was derived upon an aggregate emissions reduction goal close to 80%, which, in turn, was intended to achieve (daily) ambient air quality standards 95% of the time. Note also that the term *emission rights* is not used anywhere in the DS 4 due to the lack of a legal framework in which to base the Program. In practice, existing sources generate *reduction credits* that can then be sold in the market. For the purpose of this paper, however, we will refer to this reduction credits as emission rights.

New sources or expansion of existing sources receive no emission-rights, so they must cover all their emissions by buying emission-rights from existing sources in the "market-place" and with the corresponding approval from the Office for the Control of Emissions from Stationary Sources (PROCEFF). In addition, both existing and new sources are subject to an emission limit that cannot be exceeded under any circumstances. In the case of existing sources, the emission-rights allocation is about half this limit.

Our analysis indicates that the Offset Program is doing well from an environmental point of view given that by July of 1997, total TSP from participating sources are below the aggregate rights allocation. There are two reasons that help to explain the sharp decline in TSP from industrial sources beginning in 1997 and accelerated in later years. The first reason is fuel switching to cleaner fuels in an effort to avoid the (daily) pre-emergency and emergency episodes of significant deterioration of air quality during which some of the most polluting sources must shut down operations. The second and main reason is the rapid adoption of natural gas from Argentina, that since late 1997 has been successfully displacing alternative fuels in all sectors of the economy (i.e., residential, commercial, power generation, and industrial)[3].

From an economic point of view, however, our results indicate that the market created under the Offset Program did not develop as such.[4] Observed prices and trading volume are very different from those predicted by a simulation model of a frictionless market. With the rapid adoption of natural gas by industrial sources, the demand for emission-rights has certainly dropped, but the supply has not responded nearly as much and actual prices are still well above those predicted by the simulation model and the trading volume remains at very low levels.[5]

Large part of the poor performance of the market can be explained by: (1) regulatory uncertainty (Hahn, 1989); (2) high transaction costs (Stavins, 1995) and lengthy and uncertain approval processes (Montero, 1998); (3) low enforcement power,

---

[2] Note also that the term *emission rights* is not used anywhere in the DS 4 due to the lack of a legal framework in which to base the Program. In practice, existing sources generate *reduction credits* that can then be sold in the market. For the purpose of this paper, however, we will refer to this reduction credits as emission rights.

[3] In many ways, it resembles the effect that the unexpected expansion of the cleaner and cheaper coal from Powder River Basin had on the US SO_2 emissions trading program (Ellerman and Montero, 1998).

[4] See ILD (1999, p. 5) for a very different perspective. According to our analysis of market performance, we think that they wrongly argue that the market has proved effective in reducing emissions.

[5] According to several informal interviews, these low levels of trading are also perceived by some industry participants.

especially during the early stages of the Program; and (4) some indications of market concentration (Hahn, 1983). As a result, we observe a thin market with weak price signals and where potential sellers feel uncertain about the possibility of buying back emission-rights if future conditions require so. Not surprisingly, firms have tended to rely on autarkic compliance paying little attention to the market.

We argue that in pursuing progress toward the attainment of ambient quality standards, the environmental authority did not pay enough attention to basic institutions for the market to take off and develop like annual auctions and a more liquid currency.[6] Annual auctions help to start-up the market by sending important price signals and also give new sources access to emission-rights. Despite monitoring constraints (since continuous monitoring is not available, the authority monitors each source once a year), we see no reason for the failure to develop an "annual right" currency without banking. That would not trespass the environmental goals of the DS 4 nor impose extra burden on the regulator.

It may well be that the authority's intention was never to see a market to develop as much as to establish a mechanism to first audit and then curb TSP emissions with less resistance by industry incumbents. Because the allocation of grandfathered emissions rights creates economic incentives for incumbent sources to declare its emissions and claim the corresponding emissions rights (i.e., capture scarcity rents), we argue that the Offset Program has proved to be very effective in helping the authority to accelerate the completion of the inventory of sources and emissions during the early stages of the Program. In fact, many sources that were thought non-existent at the time the DS 4 was promulgated showed up claiming emissions rights thereafter. In this particular context of institutional limitations it is not clear that alternative regulatory instruments such as emission standards or taxes would have been as effective in this particular task of inventory completion.

Despite this important and generally less appreciated feature of grandfathered tradeable permits, the lack of attention to market development may have created an undesirable precedent for those who would like to see wider use of economic instruments in the country's future environmental policy: good environmental performance (primarily helped by the rapid, price-based introduction of natural gas) accompanied by poor market development. This precedent may be particularly

[6] Emission rights do not have an expiration date. They are allocated on permanent basis, so that the right holder enjoys the right to emit certain amount of emissions from the time she holds the emissions right.

unwelcome at this time when in January of 1999, the Executive has decided, once again, to postpone the submission to Congress of a (4 years old) draft legislation to expand the use of tradeable permits more generally. We do not see yet, how this market-based experiment can help the Executive to reduce the significant opposition that the notion of emissions trading faces among some members of Congress and other sectors of the society.

The rest of paper is organized as follows. In Section 2 we briefly describe Santiago's air pollution problems with regard to PM10 and TSP. In Section 3 we provide the basic regulatory elements of the Offset Program and its interaction with other legislation and norms. In Section 4 we discuss the evolution of emissions and emissions reductions up to July 1999. In Section 5 we develop theoretical and numerical models of a frictionless TSP market against which the Offset Program can be judged upon. In Section 6 we present data on actual prices and volume of transactions and compare them to the results predicted by the models of Section 5. We accompanied the analysis with a discussion of the possible reasons for the differences and some recommendations. Concluding remarks are offered in Section 7.

2. AIR POLLUTION IN SANTIAGO

The city of Santiago presents serious air pollution problems. In fact, in June of 1996, the Santiago Metropolitan Region was officially declared a saturated zone (or nonattainment zone) for four atmospheric pollutants including total suspended particulates (TSP), breathable particulate matter (PM10), carbon monoxide (CO) and ozone (O_3).[7] The declaration was primarily based on the fact that the daily air quality standards for TSP and PM10 had been repeatedly exceeded on one or more of the air quality monitoring stations,[8] almost on a daily basis, during the fall and winter months of recent years.

While high concentrations from all these urban pollutants have had adverse health effects in the people of Santiago, none has been nearly as bad as those from high

[7] Decree No. 131, June 12, 1996.

concentrations of PM10. High atmospheric concentration of PM10 have been observed back in the early ‘80s, but only recently (since the early ‘90s), the environmental authority has addressed this particular problem in a more systematic way as a response to the growing evidence of the possible adverse health effects. In fact, recent epidemiological studies have used data from Santiago to find strong statistical correlation between PM10 concentrations and daily mortality (Ostro et al., 1996), and between PM10 and respiratory disease among children (Ostro et. al., 1999).

As shown in Table 1, the contribution of stationary industrial sources (industrial boilers, ovens and processes) to total TSP in 1987 was 21,776 kg/day, which is 61.6% of total TSP from stationary and mobile sources. Some observers have argued that the contribution of industrial sources is much smaller because of suspended dust from paved or unpaved roads.[9] Despite that a decade later the contribution of industrial sources have declined by almost half to 34% of total TSP, by the early 90s, the authority considered the contribution from fixed-point industrial sources to be significant enough to be included in any serious effort to curb TSP and PM10 emissions.

TABLE 1.
TSP IN THE SANTIAGO METROPOLITAN REGION FOR YEARS 1987 AND 1997

Sources of Total Suspended Particulate (TSP)	TSP in 1987 (kg/day)	%	TSP in 1997 (kg/day)	%
Industrial Boilers and Ovens	9,436	26.7	4,162	17.3
Industrial Processes	12,340	34.9	4,019	16.7
Building Furnaces	573	1.6	521	2.2
Residential Heaters	4,551	12.9	3,723	15.4
Open Fires	1,200	3.4	4,197	17.4
Mobile Sources Combustion	7,290	20.6	7,482	31.0
TOTAL	35,389	100.0	24,104	100.0

For numbers on suspended dust from paved and unpaved see the text.
Source: Conama (1997a).

[8] The PM10 daily standards is 150 µg/m3 for 24 hours. It was established based on those of the US Environmental Protection Agency (EPA).
[9] Since suspended dust is mostly large particulate, it remains a very controversial issue whether it causes any serious health problems. If one includes suspended dust, total TSP jumps to 117,337 kg/day and the contribution of industrial sources drops to 18.6%.

3. THE TSP OFFSET PROGRAM

The Offset Program—established in March of 1992 under Supreme Decree No. 4 (DS 4)—was created to resolve, in a cost-effective manner, the conflict between industrial growth and progress towards meeting the ambient air quality standards for TSP and PM10 in the city of Santiago. The DS 4 also instructed the Environmental Health Service of the Metropolitan Region (SESMA), through its Office for the Control of Emissions from Stationary Sources (PROCEFF) to enforce the Offset Program.

The DS 4 regulates TSP daily mass emissions (kg/day) from generally large stationary industrial sources (primarily industrial boilers and ovens) whose emissions are discharged through a duct or chimney with a flow volume greater than or equal to 1,000 m^3/hr. According to PROCEFF (1993), the total number of affected sources by July of 1993 is 680, of which 563 are considered *existing* sources, which are sources that were registered (not necessarily operating) by the time the DS 4 became effective (March of 1992). The remaining sources correspond to *new* sources (32), which are sources not registered by March of 1992 or expansions of existing sources after that date, and other sources yet to be defined (85).

The environmental goals of the DS 4 would be accomplished in different forms and gradually over time. We now proceed to describe the different elements of the DS 4 and its interactions with related legislation. First, the DS 4 establishes a TSP *emissions concentration standard* of 112 mg/m^3 for all existing and new sources in the Program. Any individual existing or new source cannot exceed this limit by any circumstances at any time during the year. Compliance with the standard for existing sources must be achieved by December 31, 1992. Non-complying sources have to shut down their operations. The decree also established that existing sources would have to meet a tighter emissions concentration standard of 56 mg/m^3 by December 31, 1997. Since then, the standard has still been subject to revisions.[10]

Second, the DS 4 allocates *emissions rights* to existing sources by the definition of a daily emission level (EDI), measured in kilograms of TSP per day (kg/day), which

---

[10] In the Decontamination Plan for Santiago (1997), a new standard is set for existing stationary sources: 50 mg/m^3 to be met by December 31, 1999 and 32 mg/m^3 to be satisfied by December 31, 2004. Existing stationary sources that do not meet this standard will have to offset their excess emissions with other existing stationary sources.

is applicable to only industrial boilers and ovens and calculated according to the following formula

(1) $EDI\ (kg/day) = MF_{92}\ (m^3/hr) * CR_0\ (mg/m^3) * 24\ (hr/day) * 10^{-6}\ (kg/mg)$

where MF_{92} is the maximum emissions flow volume according to the source's engineering design in 1992, and CR_0 is the *emissions concentration rate* used to calculate the rights allocation, which is equal to 56 (mg/m^3) for all existing sources.

Note that (1) implicitly assumes that the source is operating at maximum capacity during 24 hours a day. This is also the assumption used to calculate each source's actual emissions and verify compliance. In fact, the regulatory authority, PROCEFF, inspects each emitting source once a year when it estimates the source's actual emissions concentration rate, CR (which depends on the source's design and fuel), and verify any change in MF. Then, the regulatory authority sets the source's actual daily emissions (EDD) equal to CR times MF multiplied by the conversion factor $24*10^{-6}$ to obtain kg/day.[11] The authority also verifies that CR is lower than the concentration standard of 112 mg/m^3. To be under compliance, a source can either, reduce emissions by decreasing MF (e.g., by demonstrating with the installation of some engineering device that the source will always operate half capacity), decrease CR by fuel switching (e.g., from coal to natural gas), or *offset* its extra emissions by acquiring emission rights from other existing sources.

Third, the DS 4 allocates no *emissions rights* to new sources—those sources registered after March 1992. This means that the entrance of new stationary sources will be authorised if and only if, the new source conforms to the emission standard of 112 mg/m^3 and *offsets* 100% of its actual daily emissions (EDD), which are calculated as before, by acquiring emission rights from other existing or new sources that may have

[11] Because almost all sources switching to natural gas install a dual system that allows them to use natural gas and petroleum #2 interchangeably but independently, in estimating EDD, the authority considers the fuel that yields the higher CR, that is petroleum #2. A source with a dual system that is planning to use only the cleaner fuel can still have its EDD estimated with the lower CR if install a (temporary) seal preventing the use of the alternative fuel.

bought extra rights. Starting in February of 1992, the Offset Program let a new source to gradually offset its emissions according to the following deadlines: offset of at least 25% of total emissions by December 31, 1993; 50% by December 31, 1994; 75% by December 31, 1995; and offset of 100% of total emissions by December 31, 1996. There are also two other elements affecting new sources. Starting in December 31, 1994, the emission standard of 112 mg/m^3 is to be reduced to 56 mg/m^3, and new sources registered after April 6, 1998, must offset 120% of their emissions.

Fourth, emission rights cannot be banked. Therefore, emissions allowed for one day cannot be emitted on another day. The purpose of this restriction is to avoid the synchronisation of emissions on a particular day that may provoke the surpassing of the air quality standards. Since rights are allocated on daily basis, in theory sources could trade daily. But because of monitoring constraints from the annual visits, sources trade on annual basis or more generally on permanent basis, as we shall see.

Fifth, the DS 4 granted SESMA the right to determine the EDI’s for all the industrial *processes* different from industrial boilers and ovens and on which expression (1) cannot be directly applied. In practice, this has meant that industrial processes have been excluded from the offset system. Considering that the *processes* have as much share of total TSP as industrial boilers and ovens, this exclusion reduces the scope of the system substantially.[12]

Sixth, the DS 4 interacts closely with the DS 32 promulgated in 1990, which controls emissions from fixed-point sources during the so-called pre-emergency and emergency episodes of bad air quality in Santiago.[13] The same stationary sources regulated under the Offset Program can be forced to shut down operation during these emergency periods if they are among the most polluting sources that are held responsible for 50% (30% during pre-emergency episodes) of the total mass emissions from stationary sources. Thus, an important reason for switching to cleaner fuels, such as natural gas, may be an effort to drop from the list of most polluting sources that are subject to sudden interruption during bad air quality episodes. Because these episodes

[12] Personal communication with environmental authorities indicates little interest in including processes yet. The main reason seems to be monitoring limitations.
[13] Pre-emergency is declared when the air quality index for particulate matter (ICAP) reaches the level of 300 (equivalent to an ambient concentration of PM10 of 240 $\mu g/m^3$), and emergency is declared when the ICAP reaches 500 (equivalent to 330 $\mu g/m^3$).

are not so rare from a business perspective,[14] this seems to be an important reason for switching to cleaner fuels.[15]

Finally, the DS 4 also interacts with the Decontamination Plan for Atmospheric Pollution in the Santiago Metropolitan Region promulgated in January 1998 because now constitutes the main instrument to regulate air pollution in Santiago.[16] It will affect the performance of the Offset Program in the future for different reasons. First, the CR_0 to estimate the EDI for existing industrial boiler and ovens will be reduced to 32 mg/m^3 in a period of 6 years. Second, if the monitoring limitations are worked out, it will define the EDI's for processes and will eventually include them in the Offset Program. And third, the Offset Program will be eventually expanded to regulate other pollutants such as CO, NOx and VOCs.

4. EMISSIONS AND EMISSION REDUCTIONS

In this section we explain the evolution of emissions and whether or not the environmental goals set by the DS 4 have been achieved. Data on the number of sources, date of registration, size (MF), fuel, concentration (CR), and rights allocation are from PROCEFF databases for years 1993 through 1999.[17] Because the inventory of sources and emissions was far from complete at the time the DS 4 was promulgated in March 1992, one of the main tasks during the preparation of this paper was to keep track of each source throughout the years. For example, some sources that did not show up in the 1993 PROCEFF's database appeared in later databases indicating that the source was in operation and already registered by March 1992, and consequently it was an existing

[14] During 1997, for example, there were 13 pre-emergency and no emergency episodes concentrated between May and September.

[15] Victor Turpaud (Metrogas), personal interview, October 1999. Note that as firms switch to cleaner fuels the concentration cutting point also falls because the mass percentage remain fixed. Today the cutting point for an emergency episode is 31 mg/m^3, which in practice means that only sources with natural gas and some others with petroleum #2 do not become affected.

[16] For full description see Conama (1997b).

[17] Note that the database of year 1993, for example, corresponds to data released by PROCEFF in July of that year with information collected during the last 12 months. There are couple of further points. First, there was no database for 1994. And second, we were warned by PROCEFF about the lower quality of the information in the 1995 and 1996 databases.

source eligible for receiving emission rights.[18] In our database we proceed to allocate rights to all these sources according to (1).

In another example, there are sources that appeared in the 1993 database as existing sources and apparently with rights already allocated, that did not show up in the 1996 database or appeared not operating, and that finally appeared as retired or simply did not show up again in the 1997 database. Unless we were able to corroborate with PROCEFF that the source sold their rights before retiring, for the construction of our database we proceed to eliminate its rights from the market. There are other examples of some sources that were in some databases but not in others, or sources that were registered twice during the first years.[19]

In general, the process of building the inventory of sources and emissions was quite difficult given the limited resources of the regulatory agency. At the same time, it was enormously facilitated by the use of grandfathered emissions rights which created the incentives for incumbent firms to declare their sources and emissions, and claim the corresponding rights (i.e., capture scarcity rents). In the context of limited agency resources, it is not clear that an alternative regulatory instrument such as taxes or emission standards would have been as effective in helping to the completion of the inventory.

Building upon PROCEFF databases and taking into account for the above and other data irregularities that we shall explain shortly, in Table 2 we present a summary of *our* database with the main variables during the period 1993-1999.[20] By July 1993, there was a total of 680 sources registered in the Program, split between existing, new and "not defined" sources. Because many sources that were thought non-existent at the time the DS 4 was promulgated showed up claiming emissions rights thereafter, PROCEFF decided to left the 85 "not defined" sources for further review. As it turned out later on, some of these sources were doubly registered, possibly but not always by

[18] This information was confirmed by PROCEFF saying that most of this sources received their allocation of rights and others are in the review process for allocating the rights.
[19] From several conversation with people at PROCEFF during 1997-1999.
[20] Our database does not include Nueva Renca because it followed a different emissions offsetting procedure than the rest of the new industrial sources affected by the Offset Program. Nueva Renca is a combined cycle power plant four times bigger (MF=766,032.9 m^3/hr) than the biggest of the existing industrial sources (MF=183,739.5 m^3/hr) that entered in operation in October 1997 and appeared in the PROCEFF's 1999 database.

mistake,[21] others simply disappeared in the subsequent databases and others achieve the status of new sources (instead of existing as they originally claimed) because of important expansions. After seven years, all sources are clearly defined between new and existing.

TABLE 2.
SUMMARY STATISTICS OF AFFECTED SOURCES: 1993-1999

Variable	1993	1995	1996	1997	1998	1999
No. of sources	680	690	631	576	566	573
Existing	563	551	504	430	365	365
New	32	101	117	136	193	208
Not defined	85	38	10	10	8	0
Flow (F_{max}) (m^3/hr)						
Total	3,344,169.3	3,301,020.1	2,910,523.5	2,339,767.5	2,385,089.6	2,375,988.7
Average	4,910.7	4,784.1	4,612.6	4,062.1	4,213.9	4,146.6
Standard Dev.	15,058.8	14,908.0	15,490.9	9,498.6	13,091.0	11,793.5
Max.	261,383.9	261,304.7	261,304.7	182,843.0	207,110.6	183,739.5
Min.	499.2	204.3	204.3	493.3	216.9	165.6
Concentration (CR) (mg/m^3)						
Average	94.9	83.1	78.5	54.7	31.1	27.8
Standard Dev.	88.1	77.8	76.8	43.0	21.1	18.5
Max.	702.0	698.2	674.0	330.7	110.0	108.2
Min.	1.5	1.5	3.4	3.6	2.9	4.6
Non-compliants	106	87	83	29	0	0
Natural gas users	0	0	0	0	145	179
Emissions (kg/day)						
EDD	7,442.5	6,500.2	5,195.1	3,535.0	1,953.6	1,636.6
EDD w/natural gas	7,442.5	6,500.2	5,195.1	3,535.0	1,742.4	1,380.3
Emission Rights (EDI) (kg/day)	4,604.1	4,604.1	4,604.1	4,087.5	4,087.5	4,087.5
Counterfactual (kg/day) ([a])						
(1) no natural gas	6,158.6	5,954.5	5,062.4	4,202.2	4,077.9	4,141.8
(2) w/natural gas	6,158.6	5,954.5	5,062.4	4,202.2	3,203.7	2,764.2
(3) 96 flow & (1)	6,158.6	5,954.5	5,062.4	4,493.8	4,227.4	4,302.5
(4) 96 flow & (2)	6,158.6	5,954.5	5,062.4	4,493.8	3,404.5	3,029.4

([a]) See text for more detail on counterfactuals.
Source: Elaborate from PROCEFF

[21] Rent seeking behavior can also explain part of the double registration.

The size of sources, measured by the maximum flow (MF), varies widely across sources. For any year, the standard deviation is well above the average.[22] Among the smaller sources, it may seem strange to observe sources below the 1,000 (m^3/hr) mark. These are existing sources that by March 1992 their MF were above 1000 (m^3/hr) and that later on, reduce MF but decided to remain in the Program to keep the emissions rights already received by 1992.

The aggregate MF also varies significantly overtime. It is particularly notorious the drop in 1996 and then in 1997. One plausible explanation is that some existing sources may have decided to reduce their MF to drop out of the Program, and that, whenever possible, some of the new sources were split into smaller units to avoid becoming affected by the Program. Although we cannot test this individually, we can do it in an aggregate way using PROCEFF databases for smaller stationary sources not affected by the Offset Program but still affected by the 112 mg/m^3 standard and the pre-emergency and emergency episodes. The summary of these smaller sources is presented in Table 3, which indicates that despite the number of sources have increase over time (but at lower rate compared to larger sources of Table 2), the total maximum flow MF has remained pretty much unchanged except for the peak of 1997.[23] This observation tends to suggest that the shift from large to smaller capacity size in order to bypass the Offset Program has not been important.

Continuing with Table 2, the concentration of affected sources also varies widely across sources and overtime. While some sources where in compliance since the first day of the Program, many others were above the standard of 112 mg/m^3 until 1997, as shown under the row of "non-compliants." This provides clear evidence of the enforcement problems experienced during the first years of the Program. The adoption of cleaner fuels lead to an important decrease in concentration, particularly after the

---

[22] Recall that to be consistent with the procedure used by PROCEFF to estimate daily emissions, MF of sources switching to natural gas is estimated assuming the use of the duel fuel (i.e., petroleum #2). This increases MF for these sources in only 1.145 times from an average of 9452 (m^3/hr) to 8255 (m^3/hr).
[23] We cannot discard that the 1997 peak is due to data collection and processing problems.

introduction of natural gas in 1997.[24] This fuel, imported from Argentina, is coming at such convenient prices that by July of 1999, 179 out of 573 sources have already switched to it.

TABLE 3
SUMMARY STATISTICS OF NON-AFFECTED SOURCES: 1993-1999

Variable	1993	1997	1998	1999
No. of sources	1616	1856	1963	1989
Flow (F_{max}) (m^3/hr)				
Total	774,366.2	861,045.0	776,122.8	788,840.0
Average	478.9	462.7	394.4	395.2
Standard Dev.	461.3	412.0	237.4	232.1
Max.	6,654.0	5,318.6	1,220.0	1,065.6
Min.	0.0	0.0	0.0	0.0
Concentration (CR) (mg/m^3)				
Average	39.4	37.1	35.3	33.2
Standard Dev.	20.0	12.8	10.8	9.6
Max.	469.9	189.3	107.8	89.8
Min.	1.5	3.8	5.7	4.1
Natural gas users	0	0	43	86
Emissions (kg/day)	789.5	809.5	646.4	621.6

Source: Elaborated from PROCEFF

According to cost analysis done by different consultants and firms, all switches to natural gas have been done primarily on economic basis independent of the DS4.[25] However, one can question this argument if looks at actions taken by smaller sources not affected by the DS 4. Table 3 shows that by 1999 only a small fraction of these smaller sources (86/1989) have switched to natural gas. The main reason for the difference in adoption rates among small and large sources is that the latter benefit greatly from economies scale resulting from the fixed cost of switching and have access to price discounts for large purchases.[26]

[24] Recall that to be consistent with the procedure used by PROCEFF to estimate daily emissions, the concentration rate CR of sources switching to natural gas is estimated assuming the use of the duel fuel (i.e., petroleum #2). This increases the actual concentration for this sources in 1.95 times from an average of 10.3 (mg/m^3) to 20.1 (mg/m^3), still well below $CR_0 = 56$ (mg/m^3).
[25] For example, Victor Turpaud (Metrogas), personal interview, October 1999.
[26] Victor Turpaud (Metrogas), personal interview, October 1999.

The combination of lower capacities (flows) and concentrations has lead to a sharp decline in emissions (EDD) overtime as shown in the next line of Table 2. Because the procedure developed by PROCEFF to estimate EDD in sources that are switching to natural gas is to use the dual fuel (i.e., petroleum #2) as the actual fuel, we also include an estimation of total emissions using natural gas (EDD w/NG) for the switching sources. Whether we take EDD or EDD w/NG, it is clear that the environmental goals established in the DS 4 have been largely accomplished if one looks at the aggregate emission limits imposed by the Offset Program (EDI).[27] It is particularly puzzling, however, that given the low enforcement levels observed in 1997 the environmental goal was achieved even before the introduction of natural gas.

In an effort to separate the effect of the Offset Program and its market on the observed emissions path from other factors such as the introduction of natural gas, we develop four (4) different counterfactual emissions paths. These are hypothetical emissions paths that would have been observed in the absence of the Offset Program but assuming that each source complies with the concentration standard of 112 (mg/m^3). To construct the first counterfactual, we assume that MF is not affected by the Offset Program and that sources keep their CR observed in 1993 from then on.[28] For new sources entering in 1993 we use their own CR of that year (not such a bad assumption given the large enforcement problems), and for new sources entering after 1993 we use the average CR of the new sources entering in 1993.[29] Because the first counterfactual neglects natural gas, in the second counterfactual we add that all switches to natural gas are price-based and consequently would have taken place regardless of the Offset Program, as we already discussed. In a way to control for the important drop of MF in 1997, which some observers may attribute it to the Offset Program because enforcement only begun to improve after that date, in the third and fourth counterfactuals we assume that individual MF for years 1997, 1998 and 1999 are that of 1996.

[27] The total number of EDIs has decreased overtime because some existing sources that had allocated emissions rights by 1993 disappeared later on with their rights, which were never sold. Note that our aggregate numbers of EDIs are very close to those provided by PROCEFF in July of 1999 indicating a total of 3,981.6 EDIs allocated to 401 sources. To get from PROCEFF's figure to ours, one must deduct from PROCEFF's those EDI allocated to sources that disappeared by 1997 and never sold their rights (so they are no longer available in the market) and include some existing and active sources that are still in the process of claiming their EDIs.

[28] We took CR = 112 for source with CR >112. The average CR is then 74.0 (mg/m^3)

[29] The average CR is equal to 70.6 (mg/m^3) and is taken over the 33 new sources in 1993 and 13 of the not defined sources of 1993 that later on resulted to be source expansions.

During the period 1993-96 actual emissions (EDD) are always higher than any of the counterfactuals. This is because in all four counterfactuals we assume that all sources are complying with the standard of 112 mg/m^3, which is certainly not the case in practice. In 1997, actual emissions (EDD) are below than any of the counterfactuals, which tends to suggest that this is the first time the Offset Program is beginning to bind. However, actual emissions (EDD) are even below the total number of emission rights (EDI) suggesting instead some sort of market inefficiency given that emission rights cannot be banked for future use.[30] If we do not want to accept the market inefficiency (or autarkic compliance) hypothesis to explain the lower concentration rate in 1997, it must be that the possibility of facing an emergency episode or the eventual presence of a cleaner and cheaper fuel (other than natural gas) motivated some sources to switch to cleaner fuels. While the former is an important factor as confirmed by industry participants, the latter does not have any empirical support.

The arrival in 1997 of natural gas at very convenient prices lead many sources to switch to that fuel. Consequently, counterfactual emissions (2) and (4), and particularly actual emissions (EDD) are well below the emissions limit (EDI). Because by July 1999 almost all affected sources for which was economical and technically feasible to switch to natural gas already did so,[31] we argue that the difference between the actual emissions and counterfactuals either (2) or (4) can explained by a mix of a possibility of facing emergency episodes and autarkic compliance.

At this point, it is possible to put forward two hypotheses. The first is that the aggregate emissions limit Offset Program has been never binding because of both the emergency episodes and the introduction of natural gas. If this were correct, the low emissions level observed would simply be an economic response to these factors exogenous to the Program. In other words, the most accurate counterfactual would be actual emissions. The second hypothesis is that beyond the effect of the emergency episodes and the introduction of natural gas on emissions, some firms are complying with the Offset Program in an autarkic way paying little attention to the emissions market. If this were correct, the over-reduction of emissions (or overcompliance) below counterfactual emissions would be an inefficient economic response to Program.

---

[30] Overcompliance can be optimal in the presence of banking (see Schmalensee et al., 1998).
[31] Victor Turpaud (Metrogras), personal interview (October 1999).

Because in order to accept the first hypothesis is still required to observe an emissions market with some important trading activity and prices reasonably low, in the next 2 sections we will develop some theoretical and numerical exercises to test market performance. A poor market performance would be a clear indication that the pattern of emissions and emissions reductions is more compatible with the second hypothesis.

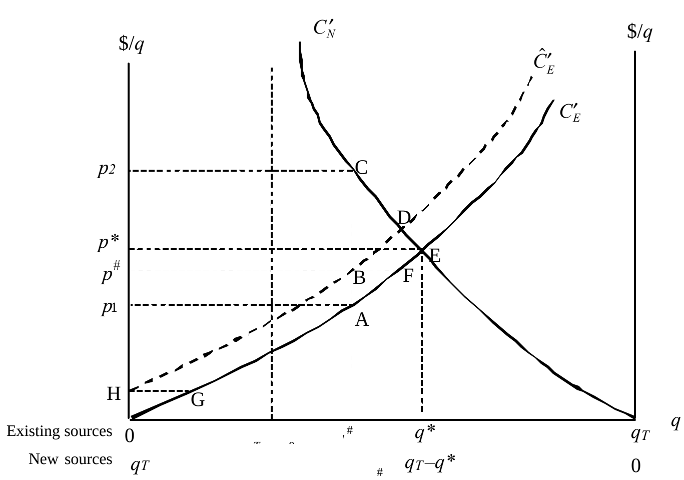
5. MARKET PERFORMANCE: THE THEORY

Our objective here is to build a reasonable theoretical and numerical benchmark against which the actual performance of the “market” (i.e., prices and the volume of transactions) created under the Offset Program can be judged upon. Such framework is intended to reflect the rules described in the previous section and the economic conditions exogenous to the market.

5.1 A simple theoretical model

In Figure 1 we depict the simplest one-period model that can be used to frame our discussion. There are two groups of emitting sources—existing and new sources—that together are subject to an aggregate level of TSP reduction of q_T, which is the difference between total counterfactual emissions (i.e., TSP emissions that would have been observed in the absence of the Offset Program) and the emission-rights allocated to existing sources. Given that an existing source’ counterfactual emissions is the emission limit, which is not fully covered by their rights allocations, and a new source does not receive emission-rights, q_T will be the sum of counterfactual emissions from new sources, e_0, and the difference between aggregate emission limit and emission-rights from existing sources. In other words, under this allocation and in the absence of trading, existing sources must reduce $q_T - e_0$, while new sources must reduce all their emissions, that is e_0.

FIGURE 1
MARKET CLEARING



The diagram in Figure 1 is arbitrarily drawn such that the origin of the aggregate (long-run) marginal control cost curve for the group of existing sources (C'_E) is the left-hand axis and the origin of the aggregate (long-run) marginal cost curve for the group of new sources (C'_N) is the right-hand axis. So drawn, the diagram gives all possible allocations of the total q_T units of emissions reductions between the two group of sources. If the market is in long-run equilibrium,[32] the clearing price of a frictionless market would be $p*$ and the cost-effective amounts of reductions would be $q*$ and $q_T - q*$ for existing and new sources respectively. Since new sources do not receive emission-rights, the "cost-effective" volume of trading would be $e_0 - (q_T - q*)$. Thus, new sources' remaining emissions must be covered completely by additional reductions (i.e., below the allowance allocation) from existing sources.

Suppose now that the total amount of trading that actually takes place is lower than the "cost-effective" volume and equal to $e_0 - (q_T - q^\#)$, where $q^\# < q*$.[33] The price that satisfies this new (imperfect) market equilibrium can be anywhere between p_1 and p_2. It cannot be lower than p_1 because at the margin there cannot be a seller willing to receive less than p_1 when the total amount of emission-rights supplied is $e_0 - (q_T - q^\#)$. Similarly, this new price cannot be higher than p_2 because at the margin there cannot be a buyer willing to pay more than p_2 when the amount of emission-rights demanded is $e_0 - (q_T - q^\#)$.

It is tempting to argue that the efficiency losses after observing reductions from existing sources equal to $q^\#$ instead of q^* would be the area ACE, regardless of the new price. However, that is a lower bound. Let us suppose that the new "equilibrium" price is $p^\#$ (in Figure 1 it shown lower than $p*$, but it could also be higher than $p*$). Since at $p^\#$, all suppliers with marginal costs below $p^\#$ are willing to sell emission-rights, there exists the extreme possibility that the amount $e_0 - (q_T - q^\#)$ is supplied along the marginal cost curve $\hat{C}'_E$, which does not include the lowest cost emitters (distance BF = HG). Thus, inefficiency losses after observing the pair ($q^\#$, $p^\#$) instead of the pair (q^*, p^*) can be anywhere between area ACE and area OHBCE.

---

[32] Montero and Ellerman (1998) explains the distinction between short-run and long run equilibrium in the context of the SO_2 allowance market. This is an important distinction to explain market performance with long-lived "control technologies" like long term fuel contracts.

In the next sub-section, we use this framework to study market performance for two cases: before and after the introduction of natural gas. Specifically we want to compare actual prices and trading activity [$p^{\#}$, $e_0 - (q_T - q^{\#})$] with frictionless levels [p^*, $e_0 - (q_T - q^*)$].

5.2 Numerical data and results

Data on different counterfactual emissions are from Table 2. Marginal cost curves were built using a mix of engineering bottom-up and econometric approaches based on information from domestic literature and many in-situ interviews with sellers of control equipment and industry operators.[34] Besides changing maximum flow capacity MF, TSP emissions can be abated either by installing end-of-pipe technology (e.g., filters, electrostatic precipitators, cyclones and scrubbers) or by fuel switching (e.g. from wood, coal or heavy oil to light oil, liquid gas or natural gas).[35]

In order to understand the evolution of the Program and the effect of the introduction of natural gas, we split the analysis in two parts. Since first switches to natural gas by industrial sources occurred by the end of 1997, in the first part we simulate a static "before gas market" using data from the 1997 database and assuming that natural gas was not available and not expected to be. In the second part, we simulate a static "after gas market" using data from the 1999 database and considering the availability of natural gas and all long-lived abatement technologies already installed by 1997.

In Table 4 we present summary information on counterfactual emissions, emission rights (EDI) and reduction requirements (q_T) for the before and after market simulations, followed by the frictionless market equilibrium results. The exercises shown in the Table are for counterfactuals 2 and 4. If we neglect the availability of natural gas whatsoever, the "before gas market" simulation indicates an equilibrium price between 6,600 and 12,600 and a large volume of trading of about 1,800 kg/day,

---

[33] Note that in theory we cannot rule out the case in which the amount of trading is greater than q^*, but that is a remote possibility given the initial allocation of emission-rights used in the Offset Program.

[34] We gathered data for a sub-sample of 255 existing sources and 49 new sources that was then extrapolated for the whole sample.

[35] It is important to note that the effect of pre-emergency and emergency episodes on sources marginal abatement costs is not included in the analysis.

which is roughly 45% of total EDI. With the price-based introduction of natural gas, the "after gas market" simulation yields an equilibrium price of zero (because at the aggregate level there are no reduction requirements) accompanied by a still high volume of trading close to 30% of total EDI. Even if the price falls to zero, there are 333 sources—including 208 new ones—that must cover their (counterfactual) emissions with rights.

TABLE 4
NUMERICAL DATA AND RESULTS

Market	Counterfactual kg/day	Total EDI kg/day	q_T kg/day	p^* $/(kg/day)	volume kg/day
Before Gas	4,202.2 (2)	4,087.5	114.7	6,600	1,844.9
	4,493.8 (4)	4,087.5	406.4	12,600	1,779.1
After Gas	2,764.2 (2)	4,087.5	< 0	0	1,112.3
	3,029.4 (4)	4,087.5	< 0	0	1,164.9

Source: Elaborated by the authors.

6. MARKET PERFORMANCE: THE PRACTICE

In this section we examine whether actual prices and volume of transactions depart in any important way from those predicted by the above theoretical results. We also offer a discussion of possible explanations and recommendations.

6.1 Actual observations on emissions prices and transactions

Tables 5 and 6 show data on prices and volume of transactions, respectively, that we were able to collect during last 2 years from different sources. Before comparing these numbers to those predicted by the simulation models we need to explain two issues. First, all market transactions but one have been of the type so-called "permanent right." A permanent right of x kg/day gives its owner the "right" to emit x kg of TSP per day indefinitely or until the Offset Program suffers any change. The only temporal trade took place in December of 1996 and was to cover TSP emissions in only one year.[36] Second, trading activity reported in Table 5 corresponds to inter-firm trading only (i.e., between unrelated firms),[37] and the total amount without including the 1 year trade is 29.75 kg/day. Even without the many non-reported quantities of Table 5, the latter number is much larger than amount of 3 kg/day of approved inter-firm transactions reported in Table 5. This is because some of the transactions of Table 5 correspond to sales not directly involving an offset and others to transaction still under review by PROCEFF, which clearly shows the length involved in each offset approval.

TABLE 5
ACTUAL PRICES AND TRANSACTIONS BY JULY 1999

Date	price 1998 US$	volume kg/day	Type of transaction
Dec-96	16,558	N.A.	permanent right
Dec-96	17,031	N.A.	permanent right
Dec-96	14,193	0.9	1 year right (*)
Apr-97	11,158	N.A.	permanent right
Sep-97	12,274	1.2	permanent right
Dec-97	35,705	N.A.	seller's posted price
Mar-98	5,895	2	permanent right
Mar-98	11,579	1	permanent right
Mar-98	11,579	N.A.	seller's posted price
Jun-98	6,316	N.A.	permanent right
Jun-98	6,316	3.65	permanent right
Jul-98	8,421	7.3	permanent right
Aug-98	3,158	14.6	permanent right
Oct-98	4,211	N.A.	seller's posted price

(*) This is sale of 1 year right at $1,419 that we convert to a sale of a permanent right using a 10% real discount rate.
Sources: Elaborated from information provided by Ambar (Alejandro Cofré), El Mercurio, Gestión Ambiental, Metrogas, PROCEFF and SESMA.

While actual prices from December 1996 through the end of 1997 does not depart in a very significant way from what predicted by the “before gas market” simulation, the volume of trading is only 9% when we include only the approved transactions (159.7/1844.9) and 18% when we include all transactions (337.1/1844.9). The introduction of natural gas has had an important effect on actual prices but they are

[36] We were informally told that the 1-year-right was for an old plantthat had to cover emissions for one more year before being retired.
[37] Otherwise there would not be a price.

still high if counterfactual emissions are estimated to be below the emissions limit as already shown in the “after gas market” simulation. A further indication of market inefficiency would be that the volume of trading observed is still far below of what predicted by the model.

One may argue that the high price of rights and lower volume of trading is because firms are holding to their rights given the stricter TSP limits of the Decontamination Plan for Santiago. Apparently, the Plan reduces the total number of rights in possession of existing sources by tightening CR_0 of (1) from 56 to 50 mg/m^3 during 2000-4 and to 32 mg/m^3 thereafter.[38] This implies that the total number of EDIs in the market will drop the most to 3,649.6 kg/day during 2000-4 and to 2,335.7 kg/day thereafter. Despite that a counterfactual higher than the 2005 limit could still support today’s positive prices, the question of overcompliance well below these stricter limits still remains.

While some of the significant overcompliance can be the result of an economic response to the probability of facing emergency and non-emergency episodes, we argue below that there are several elements affecting the performance of the market that are responsible for the overcompliance observed. Before moving on to the next section, it is important to make clear that we are not arguing that the net benefits of overcompliance are necessarily negative (see, e.g., Oates et al, 1989), but that overcompliance is a symptom of market imperfection.

6.2 From theory to practice

Here we discuss the elements that we believe are affecting the performance of the market and offer a few recommendations where we think there is room for improvement.

Regulatory uncertainty. The first problem faced by the environmental authorities after the publication of the DS 4 in March of 1992, was the urgent need to develop the institutional capabilities to regulate fixed sources which was totally lacking at the moment. PROCEFF was established with the specific tasks of compiling a comprehensive and detailed registration of the point sources, considering their emission levels and concentrations, and of developing the rules for the laboratories of measurement and analysis under the principles of free entry subject to the fulfilment of a number of specific technical requirements. The registration and control of emissions from fixed sources permitted the collection of information about the existence of a number of sources that had not been previously identified and whose contribution to the total emission of particulate matter had not been quantified before.

On the one hand, this registration and inventory process was perhaps one of the most important achievement of the Offset Program since it permitted the identification and inspection of all the fixed sources including those that emit more than the established standards. On the other hand, it also revealed important differences between initial inventories of emissions and actual emission, raising an important policy issue for the implementation of tradable permit schemes that has to do with the initial allocations of rights.

In the case of the DS 4, the allocation of rights was made to all existing sources, implicitly recognising the existence of historical rights. However, when this criteria is used for the initial allocation of emission-rights, there has to be a very precise idea of the number of existing sources and their size. This was not the case in the Offset Program. A significant number of new sources appeared creating great uncertainty around the Program and the possibility of trading. This uncertainty led PROCEFF to concentrate all its regulatory activity in the quantification of sources and emissions and, consequently, no offsets were authorised during the first 3 years of the Program.

Later on and particularly after the introduction of natural gas in late 1997, the authority has come to realise that the initial allocation of rights was too generous. In an effort to revert this situation, new sources registering after June 1998 must offset 120% and the Decontamination Plan of Santiago includes new provisions that reduce the number of existing rights in a way yet to be defined more precisely. All this regulatory uncertainty has been enhanced by recent intentions from part of the authority to study the possibility of increasing the offset requirements of new sources to 150%.

High transaction costs and lengthy and uncertain approval processes. Transaction costs are high because the procedures under which the system operates are far from simple and for that same reason the approval process is uncertain. Two pieces

---

[38] It is not clear yet whether the tightening of the limit will be done considering all allocated rights or only

of evidence are found in Table 6. The amount of intra-firm trading is much larger than the amount of inter-firm trading, and there is a large proportion of transactions still under review. Also, the high transaction costs are the result of substantial searching costs, given that there is no formal organised market for these emission rights.

Low enforcement. Because of limited resources, enforcement has been very weak throughout the Program. During the first years, there were enforcement problems with regard to both the concentration standard of 112 mg/m^3 and the accounting of emission rights that each source must hold to cover its emissions. After 1997, the first problem was resolved but enforcement problems in the reconciliation of rights and emissions has remained as shown in Table 6 if one compares the total volume of trading of 337.1 kg/day and the total amount of 427.6 kg/day of rights required from new sources.[39]

TABLE 6
VOLUME OF TRANSACTIONS BY JULY 1999

	# sources	kg/day
Total rights (EDI) allocated	401	3,981.3
Approved offsets	32	159.7
Internal (intra-firm) offsets	30	156.7
External (inter-firm) offsets	2	3.0
Internal/external offsets under review	27	104.5
Sales not involving an offset	10	72.9
Total trading activity	69	337.1
Required offsets from new sources by 1999	208	427.6

Source: Elaborate from data provided by PROCEFF.

Market power. Another critical feature of the scheme under analysis is the high concentration of EDI's that has occurred. If we group the sources according to ownership using the Internal Revenue Service Number which is reported in the register, it turns out that 21 firms (not sources) own 50% of the total EDI's, and the first 5 firms own 31% of allocated emission-rights. This figure show that the market has a degree of

those in possession of existing sources.

[39] Enforcement is improving as later figures released by SESMA in November 1999 indicate an important increase in total trading activity to 488.96 kg/day. The largest increase is in the number of offsets under review to 246.44 kg/day. Approved offsets increased to 161.13 kg/day and sales not involving an offset to 81.39 kg/day.

concentration that could explained part of the lower supply of emission-rights and the high price (Hahn, 1983).

Thin market. One reason is that sellers are not willing to sell because of uncertainty of being able to buy back emission-rights in the future if needed for an expansion of existing sources or installation of new sources. The second reason is due to monitoring constraints. Because it is not possible to monitor TSP emissions on a daily basis, the environmental currency has become a “permanent right” instead of a “daily right,” significantly reducing the liquidity of the market. The implication is that in a thin market buyers pay higher prices closer to their reservation prices and consequently higher than competitive prices which is entirely consistent with what is observed in the Offset Program.

It seems that the authority did not pay enough attention to basic institutions for the market to take off and develop like annual auctions and a more liquid currency. Annual auctions help to start-up the market by sending important price signals and also give new sources access to emission-rights. In an effort to see more of the 1 “year right” of Table 5, we see no reason why an “annual right” currency with no banking could have not been instituted in the first place. This would not have trespassed the environmental goals of the DS 4 nor imposed extra burden on the regulator given the monitoring constraints.

Low scope of the Program. The question of which sources are permitted to enter the system becomes particularly relevant, especially when considering that industrial processes, which account for more than 50% of particulates originated from stationary sources, have been left out of the system. On the one hand, this exclusion creates additional market uncertainty because of the possibility that at some point in the future these sources become affected and enter the market as either net buyers or net sellers, affecting expectations about future market prices. On the other hand, this exclusion reduces the liquidity of the market. As a direct policy implication, to promote the generation of an active and competitive market for emission-rights, more sources of particulate matter that are currently or about to be regulated under some command-and-control approach should be included in the system starting with the industrial processes. It might even be necessary to work on how to include in the system, the mobile sources that are heavy emitters of PM10, especially diesel powered buses.

7. CONCLUSIONS

In recent years there has been a widespread interest in the use market-based instruments—particularly emissions trading or tradable permits systems—to deal with air pollution problems, rather than the more traditional command-and-control approach of emission and technology standards. The purpose of this paper has been to provide an evaluation of the "emission-offsets trading program" established by Supreme Decree No. 4 (DS 4) in March of 1992 to control total suspended particulate emissions (TSP) from stationary (industrial) sources in Santiago, Chile.

Our analysis indicates that the Offset Program is doing well from an environmental perspective thanks to factors exogenous to the Program such as the price-based introduction of natural gas. From an economic perspective, our results indicate that the market created under the Program has poorly performed due to regulatory uncertainty, high transaction costs, lengthy and uncertain approval processes and low enforcement power. Despite the poor market performance, the allocation of grandfathered emissions rights has created economic incentives for incumbent sources to more readily declare their emissions and claim the corresponding emissions rights (i.e., capture scarcity rents) helping the authority to accelerate the completion of the inventory of sources and emissions.

It is unfortunate that in pursuing progress toward the attainment of ambient quality standards, the environmental authority did not pay enough attention in setting the conditions for the development of the market. This lack of attention to market development may have created an undesirable precedent for those who would like to see wider use of economic instruments in the country's future environmental policy: good environmental performance accompanied by poor market development.

REFERENCES

National Commission for the Environment, CONAMA (1997a), Inventario de Emisiones Atmosféricas de la Región Metropolitana para 1997 y Proyecciones al 2005. Publicación Comisión Nacional del Medio Ambiente para la Región Metropolitana, Santiago, Chile.

National Commission for the Environment, CONAMA (1997b), Plan de Prevención y Descontaminación Atmosférica de la Región Metropolitana, Santiago, Chile.

Ellerman, A.D. and J.-P. Montero (1998), The declining trend in sulfur dioxide emissions: Implications for allowance prices, *Journal of Environmental Economics and Management* 36, 26-45.

Hahn, R.W. (1989), Economic Prescriptions for Environmental Problems: How the Patient Followed the Doctor's Orders, *Journal of Economic Perspectives* 3, 95-114.

Hahn, R.W. (1983), Market power and transferable property rights, *Quarterly Journal of Economics* 99, 753-765.

Jacoby, H.D., R. Schmalensee, and I. Sue Wing (1999), Toward a useful architecture for climate change negotiations, Report No. 49, MIT Joint Program on the Science and Policy of Global Change, May.

Instituto Libertad y Desarrollo (ILD, 1999), Descontaminación de Santiago: Un plan que no funciona, bulletin #442, July.

Montero, J.-P. (1998), Marketable pollution permits with uncertainty and transaction costs, *Resource and Energy Economics* 20, 27-50.

Montero, J.-P., and A.D. Ellerman (1998), Explaining low sulfur dioxide allowance prices: The effect of expectation errors and irreversibility, Working paper 98-011, MIT Center for Energy and Environmental Policy Research, Cambridge, MA.

Oates, W.E., P.R. Portney and A.M. McGartland (1989), The net benefits of incentive-based regulation: A case study of environmental standard setting" *American Economic Review* 79, 1233-1244.

Ostro, B., J.M. Sánchez, C. Aranda and G. Eskeland (1996), Air Pollution and Mortality: Results from a Study of Santiago, Chile, *Journal of Exposure Analysis and Environmental Epidemiology* 6 (1), 97-114.

Ostro, B., Eskeland, G., Sánchez, J.M., Feyzioglu, T. (1999). Air Pollution and Health Effects: A Study of Medical Visits Among Children in Santiago, Chile, *Environmental Health Perspectives* 107 (1). January.

PROCEFF (1993-99). Data bases for 1993 through 1999. Programa para el Control de Emisiones de Fuentes Fijas, Santiago.

Schmalensee, R., P.L. Joskow, A.D. Ellerman, J.-P. Montero, and E.M. Bailey (1998), An interim evaluation of sulfur dioxide emissions trading." *Journal of Economic Perspectives* 12, 53-68.

Stavins, R. (1995), Transaction costs and tradeable permits, *Journal of Environmental Economics and Management* 29, 133-148.

Tietenberg, T. H. (1985), *Emissions Trading*: *An Exercise in Reforming Pollution Policy*, Resources for the Future, Washington, DC.

World Bank (1997), *Five Years after Rio: Innovations in Environmental Policy*, Rio+ 5 Edition, Draft for Discussion, The World Bank, Washington, DC, March.

TABLE 1.
TSP IN THE SANTIAGO METROPOLITAN REGION FOR YEARS 1987 AND 1997

Sources of Total Suspended Particulate (TSP)	TSP in 1987 (kg/day)	%	TSP in 1997 (kg/day)	%
Industrial Boilers and Ovens	9,436	26.7	4,162	17.3
Industrial Processes	12,340	34.9	4,019	16.7
Building Furnaces	573	1.6	521	2.2
Residential Heaters	4,551	12.9	3,723	15.4
Open Fires	1,200	3.4	4,197	17.4
Mobile Sources Combustion	7,290	20.6	7,482	31.0
TOTAL	35,389	100.0	24,104	100.0

For numbers on suspended dust from paved and unpaved see the text.
Source: Conama (1997a).

TABLE 2.
SUMMARY STATISTICS OF AFFECTED SOURCES: 1993-1999

Variable	1993	1995	1996	1997	1998	1999
No. of sources	680	690	631	576	566	573
Existing	563	551	504	430	365	365
New	32	101	117	136	193	208
Not defined	85	38	10	10	8	0
Flow (F_{max}) (m^3/hr)						
Total	3,344,169.3	3,301,020.1	2,910,523.5	2,339,767.5	2,385,089.6	2,375,988.7
Average	4,910.7	4,784.1	4,612.6	4,062.1	4,213.9	4,146.6
Standard Dev.	15,058.8	14,908.0	15,490.9	9,498.6	13,091.0	11,793.5
Max.	261,383.9	261,304.7	261,304.7	182,843.0	207,110.6	183,739.5
Min.	499.2	204.3	204.3	493.3	216.9	165.6
Concentration (CR) (mg/m^3)						
Average	94.9	83.1	78.5	54.7	31.1	27.8
Standard Dev.	88.1	77.8	76.8	43.0	21.1	18.5
Max.	702.0	698.2	674.0	330.7	110.0	108.2
Min.	1.5	1.5	3.4	3.6	2.9	4.6
Non-compliants	106	87	83	29	0	0
Natural gas users	0	0	0	0	145	179
Emissions (kg/day)						
EDD	7,442.5	6,500.2	5,195.1	3,535.0	1,953.6	1,636.6
EDD w/natural gas	7,442.5	6,500.2	5,195.1	3,535.0	1,742.4	1,380.3
Emission Rights (EDI) (kg/day)	4,604.1	4,604.1	4,604.1	4,087.5	4,087.5	4,087.5
Counterfactual (kg/day) ([a])						
(1) no natural gas	6,158.6	5,954.5	5,062.4	4,202.2	4,077.9	4,141.8
(2) w/natural gas	6,158.6	5,954.5	5,062.4	4,202.2	3,203.7	2,764.2
(3) 96 flow & (1)	6,158.6	5,954.5	5,062.4	4,493.8	4,227.4	4,302.5
(4) 96 flow & (2)	6,158.6	5,954.5	5,062.4	4,493.8	3,404.5	3,029.4

([a]) See text for more detail on counterfactuals.
Source: Elaborate from PROCEFF

TABLE 3
SUMMARY STATISTICS OF NON-AFFECTED SOURCES: 1993-1999

Variable	1993	1997	1998	1999
No. of sources	1616	1856	1963	1989
Flow (F_{max}) (m^3/hr)				
Total	774,366.2	861,045.0	776,122.8	788,840.0
Average	478.9	462.7	394.4	395.2
Standard Dev.	461.3	412.0	237.4	232.1
Max.	6,654.0	5,318.6	1,220.0	1,065.6
Min.	0.0	0.0	0.0	0.0
Concentration (CR) (mg/m^3)				
Average	39.4	37.1	35.3	33.2
Standard Dev.	20.0	12.8	10.8	9.6
Max.	469.9	189.3	107.8	89.8
Min.	1.5	3.8	5.7	4.1
Natural gas users	0	0	43	86
Emissions (kg/day)	789.5	809.5	646.4	621.6

Source: Elaborated from PROCEFF

TABLE 4. NUMERICAL DATA AND RESULTS

Market	Counterfactual kg/day	Total EDI kg/day	q_T kg/day	p^* $/(kg/day)	volume kg/day
Before Gas	4,202.2 (2)	4,087.5	114.7	6,600	1,844.9
	4,493.8 (4)	4,087.5	406.4	12,600	1,779.1
After Gas	2,764.2 (2)	4,087.5	< 0	0	1,112.3
	3,029.4 (4)	4,087.5	< 0	0	1,164.9

Source: Elaborated by the authors .

TABLE 5
ACTUAL PRICES AND TRANSACTIONS BY JULY 1999

Date	price 1998 US$	volume kg/day	Type of transaction
Dec-96	16,558	N.A.	permanent right
Dec-96	17,031	N.A.	permanent right
Dec-96	14,193	0.9	1 year right (*)
Apr-97	11,158	N.A.	permanent right
Sep-97	12,274	1.2	permanent right
Dec-97	35,705	N.A.	seller's posted price
Mar-98	5,895	2	permanent right
Mar-98	11,579	1	permanent right
Mar-98	11,579	N.A.	seller's posted price
Jun-98	6,316	N.A.	permanent right
Jun-98	6,316	3.65	permanent right
Jul-98	8,421	7.3	permanent right
Aug-98	3,158	14.6	permanent right
Oct-98	4,211	N.A.	seller's posted price

(*) This is sale of 1 year right at $1,419 that we convert to a sale of a permanent right using a 10% real discount rate.
Sources: Elaborated from information provided by Ambar (Alejandro Cofré), El Mercurio, Gestión Ambiental, Metrogas, PROCEFF and SESMA.

TABLE 6
VOLUME OF TRANSACTIONS BY JULY 1999

	# sources	kg/day
Total rights (EDI) allocated	401	3,981.3
Approved offsets	32	159.7
Internal (intra-firm) offsets	30	156.7
External (inter-firm) offsets	2	3.0
Internal/external offsets under review	27	104.5
Sales not involving an offset	10	72.9
Total trading activity	69	337.1
Required offsets from new sources by 1999	208	427.6

Source: Elaborate from data provided by PROCEFF.