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A Market-Based Environmental Policy Experiment in Chile

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Abstract

Despite growing interest in the use of emissions trading for pollution control, empirical evidence for this regulatory instrument has been confined to a few experiences in the United States. This paper broadens the empirical base by examining the "Emission-Offsets Trading Program" that has been in place since 1992 to control airborne particulate emissions in Santiago, Chile. While the program is doing well from an environmental perspective, due in part to the price-based introduction of natural gas, the market is performing poorly because of high transaction costs, uncertainty, and poor enforcement. However, the scarcity rents created by allocating grandfathered emission rights to incumbents have proved to be a very effective tool for completing the emissions inventory.

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1. Introduction

Recent years have seen widespread interest in the use of market-based instruments—particularly emissions-trading or tradeable permits systems—to deal with air pollution, rather than the traditional command-and-control approach of setting emission and technology standards. While almost all experience with tradeable permit systems has been confined to the U.S. (Tietenberg, 1985; Hahn, 1989; Schmalensee et al., 1998), a few less developed countries (LDCs) are also beginning to experiment in different forms with emissions trading (World Bank, 1997). A close examination of these experiences right now is particularly interesting, 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 present paper evaluates the "Emission-Offsets Trading Program" established by Supreme Decree No. 4 (DS 4) in March 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 collected from 1993 through 1999, then suggest ways in which the functioning of this market might be improved within the current institutional context.

The Offset Program was established to resolve, in a cost-effective manner, the conflict between industrial growth and ambient air quality standards for TSP and breathable particulate matter (PM10) in the city of Santiago, which have been exceeded consistently since the 1970s. Under the Offset Program, *existing* sources—i.e., sources registered at the time DS 4 was promulgated—received *daily emissions capacity rights* in perpetuity proportional to a predetermined emissions rate level that is uniform across existing sources.[1,2]

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[1] Note that in the context of this paper, the term *emissions rate* refers to emissions concentration. The rate used to calculate rights allocations was derived from an aggregate emissions reduction goal close to 80%, which, in turn, was intended to achieve (daily) ambient air-quality standards 95% of the time.

A source must hold enough capacity rights to cover the maximum emissions level projected for any given day. We refer to this level as the source's *emissions capacity*. The authority determines emissions capacity based on a source's current size and fuel type, which are measured during annual inspections. In other words, what the authority measures are not actual emissions but the emissions capacity; consequently, what are being traded are not emission rights but capacity rights. Thus, after each inspection, the authority proceeds to reconcile the estimated emissions capacity with the number of capacity rights held by the source. An existing source can either be a seller or buyer of rights depending on whether its emissions capacity is below or above its grandfathered daily rights. It is important to note that despite rights being distributed daily (and in perpetuity), the monitoring limitations restrict sources to trading rights on either an annual or a permanent basis.

New sources and expansions of existing sources receive no emissions capacity rights, so must cover all their emissions capacity by buying capacity rights from existing sources. This means that there is an aggregate emissions cap equal to the sum of rights distributed to existing sources. Despite its official name, the Offset Program has then all the characteristics of a cap-and-trade or emissions-trading system but for one restriction. Both existing and new sources are subject to an emissions capacity limit that cannot be exceeded under any circumstances. In the case of existing sources, the capacity rights allocation is about half this limit.

Our analysis indicates that the Offset Program is doing well from an environmental point of view: by July 1997, total TSP capacity from participating sources was below the total number of capacity rights distributed. Two reasons help to explain the sharp decline in TSP from industrial sources that began in 1997 and subsequently accelerated. First, industry switched to cleaner fuels in an effort to avoid the daily pre-emergency and emergency episodes of significant air quality deterioration, 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; since late 1997, Argentina's natural gas has been

[2] Note also that the term *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 be sold in the market. For the purposes of this paper, however, we will refer to these reduction credits as emissions capacity rights.

displacing alternative fuels in all sectors of Chile's 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 has developed poorly. Consequently, it cannot be held responsible for the decline in emissions and accomplishment of the environmental goals.[4] Observed prices and trading volume differ significantly from those predicted by a simulation model of a frictionless market. With industrial sources' rapid adoption of natural gas, the demand for capacity rights has certainly dropped, but the supply has not responded nearly as much as could be expected. Actual prices remain well above those predicted by the simulation model, and trading volume remains very low.[5]

A large part of the market's poor performance can be explained by: (1) regulatory uncertainty (Hahn, 1989); (2) high transaction costs (Stavins, 1995) and lengthy, uncertain approval processes (Montero, 1998); (3) low enforcement power, 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, in which potential sellers feel uncertain about the possibility of buying back rights should future conditions so require. Not surprisingly, firms have tended to rely on autarkic compliance, paying little attention to the market.

We argue that, in pursuing some progress toward achieving ambient quality standards, the environmental authority did not pay sufficient attention to basic institutions for market development, like annual auctions and a more liquid currency. Annual auctions assist market start-up by sending important price signals, and give new sources access to rights. Despite the annual measurements' monitoring limitations, we see no reason why a more liquid currency (such as a daily capacity right lasting only one year, without the option of banking for future use) was not implemented in the first place. A more liquid currency would neither trespass the environmental goals of DS 4 nor impose any extra burden on the regulator. It may well be that the authority's intent was never to see a market

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[3] In many ways, the effect on the Offset Program of introducing natural gas to the Chilean economy has resembled that of the unexpected expansion of cleaner, cheaper Powder River Basin coal on the U.S. SO_2 emissions-trading program (Ellerman and Montero, 1998).

[4] The Instituto Libertad y Desarrollo (1999, p. 5) offers a different perspective. Based on our analysis, however, we think that they wrongly argue that the market has proved effective in reducing emissions.

develop so much as it was to establish a mechanism for first auditing and then curbing TSP emissions with minimal resistance from industry incumbents.

Because the allocation of grandfathered capacity rights creates economic incentive for incumbent sources to declare their emissions and claim the corresponding rights (i.e., to capture "scarcity rents"), we argue that the Offset Program has proved very effective in helping the authority complete its inventory of sources and emissions during the early stages of the program. In fact, many sources thought nonexistent at the time DS 4 was promulgated appeared, claiming rights, thereafter. In this particular context of institutional limitations, it is unclear whether alternative regulatory instruments such as emission standards or taxes would have been as effective for completing the inventory.

Despite this important and generally unnoticed feature of grandfathered tradeable permits, the lack of attention to market development may have created a precedent that is unfortunate for those who would like to see wider use of economic instruments in the country's environmental policy: good environmental performance accompanied by little market development. Hopefully, the result of this particular market-based experiment, together with the significant opposition that the notion of emissions trading faces among some members of Congress, will not discourage the Executive in its already five-year effort to pass legislation promoting the use of tradeable permits more generally.

The rest of this paper is organized as follows. Section 2 briefly describes Santiago's air pollution problems with regard to PM10 and TSP. Section 3 outlines the basic regulatory elements of the Offset Program and notes its interaction with other legislation and norms. Section 4 discusses the evolution of emissions and emission reductions (or, more precisely, emissions capacities and capacity reductions) up to July 1999. In Section 5, we develop theoretical and numerical models of a frictionless TSP market, against which some results of the Offset Program can be judged. Section 6 presents data on actual prices and transaction volumes, and compares these to results predicted by the models introduced in Section 5. We follow up this analysis with a discussion of possible reasons for the differences, and recommendations. Concluding remarks are offered in Section 7.

2. Air Pollution in Santiago

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[5] Several informal interviews have shown that the low trading levels have been noticed by some industry

The city of Santiago presents serious air pollution problems. In fact, during June 1996, the Santiago Metropolitan Region was officially declared a saturated (or nonattainment) zone for four atmospheric pollutants: total suspended particulates (TSP), breathable particulate matter (PM10), carbon monoxide (CO), and ozone (O_3).[6] The declaration was based primarily on the fact that the daily air quality standards for TSP and PM10 had been repeatedly exceeded on one or more air quality monitoring stations,[7] almost daily during the fall and winter of recent years.

While high concentrations of all these urban pollutants have adversely affected the health of people in Santiago, high concentrations of PM10 have caused the worst problems. High atmospheric concentrations of PM10 have been observed since the early '80s, but only recently (since the early '90s) has the environmental authority addressed this problem systematically in response to growing evidence of the possible adverse health effects. In fact, recent epidemiological studies used data from Santiago to find a strong statistical correlation between PM10 concentration and daily mortality (Ostro et al., 1996), and between PM10 concentration and respiratory disease among children (Ostro et al., 1999).

As **Table 1** shows**,** the contribution of stationary industrial sources (industrial boilers, ovens, and processes) to total TSP in 1987 was 21,776 kg/day: 61.6% of total TSP from stationary and mobile sources combined. Some observers have argued that industrial sources' contribution is actually much smaller than this, because suspended dust from all roads should be taken into account, as well.[8] Despite such uncertainties, a decade later, the contribution from industrial sources has declined by almost half, to 34% of total TSP; yet, by the early '90s, the authority considered contributions from fixed-point industrial sources significant enough still to be included in any serious effort to curb TSP and PM10 emissions.

3. The TSP Offset Program

participants, too.

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

[7] The PM10 daily standard is 150 μg/m^3 for 24 hours, based on standards established by the U.S. Environmental Protection Agency (EPA).

[8] Since suspended dust is mostly large particulate matter, whether it causes serious health problems remains controversial. Including suspended dust would increase total TSP to 117,337 kg/day, reducing industrial sources' contribution to 18.6%.

The Offset Program—established in March 1992 under Supreme Decree No. 4 (DS 4)—was created to resolve, in a cost-effective manner, the conflict between industrial growth and 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/h. According to PROCEFF (1993), the total number of affected sources by July 1993 was 680, of which 563 were considered *existing* sources: sources that were registered (but not necessarily operating) by the time DS 4 became effective, March 1992. The remaining sources correspond to *new* sources (32)—those sources not registered by March 1992—or expansions of existing sources that commenced operations after that date, and other sources yet to be defined (85).

Existing sources face two constraints. First, under no circumstances can the emissions concentration exceed 112 mg/m^3. In addition, existing sources are given daily emissions capacity rights (DECRs) to cover daily emissions capacity (DEC) according to the following formula:

$$\text{DECR (kg/day)} = F_0\ (m^3/h) * C_0\ (mg/m^3) * 24\ (h/day) * 10^{-6}\ (kg/mg) \qquad (1)$$

where F_0 is the maximum emissions flow volume as declared at the source's registration in 1992, and C_0 = 56 mg/m^3 is the emissions concentration "quota" used uniformly across all existing sources. Differences between the observed emissions capacity, based on maximum emissions flow (F) and the emissions concentration (C) as these vary from year to year,[9] and the grandfathered emissions capacity of expression (1) can be traded as long as the observed concentration does not exceed the maximum 112 mg/m^3 standard. Emissions

[9] Because almost all sources switching to natural gas install a dual system allowing them to use natural gas and Petroleum #2 interchangeably but independently, the authority bases its estimation of DEC on the fuel yielding the higher concentration, that is, Petroleum #2. A source with a dual system that plans to use only the cleaner fuel can still have its DEC estimated based on the lower concentration if it installs a (temporary) seal preventing use of the alternative fuel.

capacity rights will be reduced during the period 2000–04 by lowering C_0 in (1) to 50 mg/m^3 while holding F_0 constant, and from 2005 onward by tightening C_0 to 32 mg/m^3.

New sources must meet a maximum concentration standard, 112 mg/m^3 through 1994 and 56 mg/m^3 thereafter, in addition to acquiring offsets (i.e., capacity rights) from existing sources for whatever emissions capacity is associated with a new source. The amount of offset was phased in from 25% in 1993 to 100% in 1996, by a 25% increment annually. After April 6, 1998, 120% must be offset and consideration is also being given to a 150% offset rule.

The DS 4 granted SESMA the right also to determine emissions capacity for all industrial *processes* that are separate from industrial boilers and ovens, and on which expression (1) cannot be directly applied. In practice, this has excluded industrial processes from the offset system. Considering that processes generate as large a share of total TSP as do industrial boilers and ovens, this exclusion reduces the scope of the system substantially.[10]

In addition, DS 4 interacts closely with DS 32 (promulgated in 1990), which controls emissions from fixed-point sources during declared states of "pre-emergency" and "emergency" episodes of bad air quality in Santiago.[11] Stationary sources regulated under the Offset Program can be forced to shut down during an emergency (pre-emergency) episode if they are among those sources held responsible for 50% (30%) of total mass emissions from stationary sources. Thus, one important reason for switching to cleaner fuels such as natural gas may be to drop from the list of most-polluting sources subject to sudden interruption during bad air quality episodes. Because these episodes are not so rare from a business perspective,[12] exclusion from this list seems to be an important reason for switching to cleaner fuels.[13]

Finally, DS 4 interacts also with the Decontamination Plan for Atmospheric

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[10] Personal communication with environmental authorities indicates little interest in including processes yet. The main reason for their exclusion seems to be monitoring limitations.

[11] A *pre-emergency* is declared when the air quality index for particulate matter (ICAP) reaches a level of 300 (equivalent to an ambient PM 10 concentration of 240 μg/m^3). An *emergency* is declared when the ICAP reaches 500 (equivalent to 330 μg/m^3).

[12] During 1997, for example, 13 pre-emergency episodes occurred between May and September. No emergency episodes were registered during that time.

[13] According to Victor Turpaud (of Metrogas) during a personal interview conducted in October 1999. Note that as firms switch to cleaner fuels, the concentration cutting point also falls because the mass percentage

Pollution in the Santiago Metropolitan Region (promulgated in January 1998), because this plan now constitutes the main instrument for regulating air pollution in Santiago.[14] The Decontamination Plan will affect performance of the Offset Program for a number of reasons. As indicated above, the C_0 to estimate DECRs for existing industrial boilers and ovens is being reduced to 32 mg/m^3 over a period of six years. In addition, if monitoring limitations are resolved, the Decontamination Plan will define the DECRs for processes and eventually include these in the Offset Program.

4. Emissions and Emission Reductions

In this section, we explain the evolution of emissions and consider whether or not the environmental goals set by DS 4 are being achieved. To meet the aggregate goals of DS 4, sources can physically reduce their emissions by either decreasing their maximum emissions flow volume (F) or their emissions concentration (C), through either fuel switching (e.g., from coal to natural gas) or the installation of end-of-pipe technology.

Data on the number of sources and their dates of registration, maximum emissions flow volumes, fuels, emissions concentrations, and capacity right allocations were taken from PROCEFF databases for the years 1993 through 1999.[15] Because the inventory of sources and emissions was far from complete at the time DS 4 was promulgated in March 1992, one main task during the preparation of this paper was to track each source throughout the years. For example, some sources that did not show up in the 1993 PROCEFF database appeared in later databases, indicating that these sources were in operation and already registered by March 1992, and consequently were existing sources eligible for receiving emissions capacity rights.[16] For our database, we therefore allocated rights to all these sources according to expression (1).

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remains fixed. Today, the cutting point for an emergency episode is 31 mg/m^3, which in practice means that only sources using natural gas and some others using Petroleum #2 are unaffected.

[14] For a full description, see CONAMA (1997b).

[15] Note that: (1) the database for year 1993, for example, corresponds to data released by PROCEFF in July of that year, based on information collected during the previous 12 months; (2) there was no database for 1994; (3) PROCEFF warned us about the lower quality of information in the 1995 and 1996 databases.

[16] PROCEFF confirmed this information, saying that most of these sources received their allocation of rights and others are being reviewed for possible rights allocations.

As another example, some sources that appeared in the 1993 database as "existing," apparently with rights already allocated, did not show up in the 1996 database (or appeared as not operating), but finally appeared once more 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 eliminated its rights from the market. Still, other examples include sources that were in some databases but not others, and sources that registered twice during 1992-93.[17]

In general, building the inventory of sources and emissions was quite difficult, given the regulatory agency's limited resources. At the same time, the process was enormously facilitated by sources' use of grandfathered emissions rights, which create incentive for incumbent firms to declare their sources and emissions, and claim the corresponding rights (i.e., capture scarcity rents). Given the 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 the authority complete the inventory.

Building upon the PROCEFF databases and taking into account the above data irregularities as well as others that we shall explain shortly, **Table 2** presents a summary of our database, with the main variables, during the period 1993–99.[18] By July 1993, a total of 680 sources were registered in the program as existing, new, or "not defined" sources. Many sources that had not been known to exist at the time DS 4 was promulgated showed up claiming emissions rights thereafter. A review by PROCEFF of the 85 "not defined" sources determined that some were doubly registered, possibly (but not always) by mistake;[19] others simply disappeared in subsequent databases, and still others PROCEFF assigned the status of "new source" (instead of "existing," as they had originally claimed) because of important expansions. Now, seven years later, all sources are clearly defined as either "new" or "existing."

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[17] This information was gathered from several conversations with PROCEFF people during 1997–99.
[18] Our database does not include the Nueva Renca source, because it followed a different emissions-offsetting procedure than the other new industrial sources affected by the Offset Program. Nueva Renca is a combined-cycle power plant that is four times larger (F = 766,032.9 m^3/h) than the biggest existing industrial source (F = 183,739.5 m^3/h) that entered operation in October 1997 and appeared in PROCEFF's 1999 database.
[19] Rent-seeking behavior also explains some of the double registration.

Source size, as measured by maximum emissions flow volume (F), varies widely. For any given year since 1993, the standard deviation is well above average.[20] Among the smaller sources, it may seem strange to observe some below the 1,000 (m^3/h) mark. These are existing sources for which, by March 1992, F exceeded 1000 (m^3/h) but later fell; nevertheless, these sources chose to remain in the program to keep the rights they had already received.

The aggregate F also varies significantly over time. Particularly noteworthy were the drops in 1996 and again in 1997. One plausible explanation is that some existing sources may have decided to reduce their F to drop out of the program, and, whenever possible, new sources were split into smaller units to avoid being affected by the program. Although we cannot test this hypothesis for individual sources, we can conduct a test in the aggregate using PROCEFF databases for smaller stationary sources affected not by the Offset Program but by the 112 mg/m^3 standard and the pre-emergency and emergency episodes. A summary of these smaller sources is presented in **Table 3**, which indicates that, despite the increase in number of sources over time, total F has remained relatively unchanged except for the peak year, 1997.[21] This observation suggests that shifts to smaller capacity size in order to bypass the Offset Program have not been important.

Table 2 also indicates that the emissions concentrations of affected sources likewise vary widely across sources and over time. While some sources have been in compliance since the first day of the program, many others were above the standard of 112 mg/m^3 until 1997, as shown by the row of "noncompliants." This clearly evidences the enforcement problems experienced during the first years of the program. Adoption of cleaner fuels has led to an important decrease in emissions concentration, particularly after the introduction of natural gas in 1997.[22] This fuel, imported from Argentina, has been available at such low prices that by July 1999, 179 of the total possible 573 sources had switched to it.

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[20] Recall that the maximum flow F of sources switching to natural gas is estimated by assuming their use of the duel fuel (i.e., Petroleum #2), to be consistent with the procedure used by PROCEFF to estimate daily emissions. This methodology decreases F for these sources only 1.145 times, from an average 9,452 (m^3/h) to 8,255 (m^3/h).

[21] We cannot disregard the fact that the 1997 peak was due to data-collection and processing problems.

[22] Recall that, to be consistent with the procedure used by PROCEFF to estimate daily emissions, the concentration rate C of sources switching to natural gas is estimated by assuming their use of the duel fuel (i.e., Petroleum #2). This methodology increases the actual concentration for these sources 1.95 times, from an average 10.3 mg/m^3 to 20.1 mg/m^3, which is still well below C_0 = 56 mg/m^3.

According to various consultants' and firms' cost analyses, all switches to natural gas have been made primarily for economic reasons, independent of DS 4.[23] One might well question this argument, however, after a look at the actions taken by smaller sources not affected by DS 4. **Table 3** shows that in 1999, only a small fraction of these smaller sources (86 of 1989 total) had switched to natural gas. The main reason for the difference in adoption rates between small and large sources is that the latter benefit greatly from economies of scale resulting from the fixed cost of switching, and also have access to price discounts for large purchases.[24]

The combination of lower emissions flow volumes and lower emissions concentrations has led to a sharp decline in daily emissions capacity (DEC) over time, as shown by the last line of **Table 2**. Because the procedure developed by PROCEFF to estimate emissions capacity in sources that are switching to natural gas is to use a dual fuel (i.e., Petroleum #2) as the actual fuel, we also include an estimate of total DEC using natural gas (DEC w/NG) for the switching sources. Regardless of whether we consider DEC or DEC w/NG, it is clear from the aggregate emissions capacity limits imposed by the Offset Program (in terms of DECRs)[25] that the environmental goals established in DS 4 have largely been achieved. Particularly puzzling, however, is the fact that, given the low enforcement levels observed in 1997, the environmental goal was achieved that year even before sources began switching over to 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 distinct counterfactual emissions capacity paths. These are hypothetical paths that would have been observed in the absence of the Offset Program, assume that each source complies with the concentration standard of 112 mg/m^3. To construct the first counterfactual, we assume that the Offset Program does not affect F, and that sources'

[23] Victor Turpaud (Metrogas), personal interview, October, 1999.
[24] According to Victor Turpaud (Metrogas), personal interview, October 1999.
[25] The total number of DECRs has decreased over time because some existing sources that had been allocated emissions rights by 1993 disappeared later with their rights, which were never sold. Note that our aggregate numbers of DECRs very closely approximate those provided by PROCEFF in July 1999, indicating a total of 3,981.6 DECRs allocated to 401 sources. To obtain our figure from PROCEFF's, one must subtract from PROCEFF's figure those DECRs allocated to sources which disappeared by 1997 and never sold their rights (so they are no longer available in the market) and add some existing and active sources that are still in the process of claiming their DECRs.

concentrations remain unchanged from their 1993 levels.[26] For new sources entering in 1993, we use their own concentration for that year (which is not a poor assumption, given the major enforcement problems); for new sources entering after 1993, we use the average concentration for new sources entering in 1993.[27] Because this first counterfactual neglects natural gas, the second counterfactual assumes that all switches to natural gas are price-based and consequently would have taken place regardless of the Offset Program, as we have already discussed. To control for the important drop in F during 1997, which some observers attribute to the Offset Program because enforcement only began to improve after that date, the third and fourth counterfactuals set the individual Fs for years 1997, 1998, and 1999 equal to that for 1996.

During the period 1993–96, actual emissions capacities always exceeded the counterfactuals. This is because all four counterfactuals assume that all sources comply with the standard of 112 mg/m^3, which certainly hasn't been the case. In 1997, aggregate emissions capacities fell below all of the counterfactuals, suggesting that the Offset Program began to bind at this time. However, aggregate emissions capacities were below even the total number of capacity rights (DECR), indicating instead some sort of market inefficiency, given that rights cannot be banked for future use.[28] If we reject the market inefficiency (or autarkic compliance) explanation for the lower concentration rate in 1997, some sources must have been motivated to switch to cleaner fuels by the possibility that they would face an emergency episode or that a cleaner, cheaper fuel than natural gas would eventually become available. While industry participants confirm that the former was important, the latter has no empirical support.

The arrival in 1997 of natural gas at very low prices prompted many sources to switch to that fuel. Consequently, Counterfactuals #2 and 4, and particularly the total emissions capacities, fall well below aggregate capacity rights. Because by July 1999 almost all affected sources for which switching to natural gas was economical and technically feasible had done so,[29] we argue that the difference between actual emissions

[26] We assumed C = 112 for all sources for which C >112. The average C then became 74.0 mg/m^3.
[27] The average C, 70.6 mg/m^3, was adopted for the 33 new sources in 1993 and 13 sources not defined for 1993 that later proved to be source expansions.
[28] Overcompliance can be optimal when banking is permitted (see Schmalensee et al., 1998).
[29] Victor Turpaud (Metrogas), personal interview, October 1999.

capacities and either Counterfactual #2 or #4 can be explained by some mix of the emergency episode and autarkic compliance explanations.

At this point, it is possible to put forward the following two hypotheses:

1) *The aggregate capacity limit of the Offset Program has never been binding because of both the emergency episodes and the introduction of natural gas*. If this hypothesis were correct, the low emissions capacity level observed would simply be an economic response to the emergency and natural gas factors, which are exogenous to the program. In other words, the most accurate counterfactual would be that of actual emissions capacities.
2) *Beyond the effects on emissions capacity of emergency episodes and natural gas, some firms are complying with the Offset Program in an autarkic manner, paying little attention to the market.* If this hypothesis were correct, the over-reduction of emissions capacity (or overcompliance) below the counterfactuals would signal an inefficient economic response to the program.

Because the first hypothesis requires observation of an emissions market with significant trading activity and reasonably low prices, the following two sections develop theoretical and numerical exercises to test market performance. Poor market performance would clearly indicate that the pattern of emissions capacities and capacity reductions is more compatible with the second hypothesis.

5. Market Performance: Theory

Our objective here is to build a reasonable theoretical and numerical benchmark against which actual performance of the "market" (i.e., prices and transaction volumes) created under the Offset Program can be compared. Such a framework is intended to reflect the rules and economic conditions exogenous to the market that were described in the previous section.

5.1 A simple theoretical model

Figure 1 depicts the simplest one-period model that can be used to frame our discussion. Two groups of emitting sources—existing and new sources—are subject to an aggregate level of TSP reduction, q_T, which is the difference between total counterfactual emissions (i.e., the TSP emissions that would have been observed in the absence of the Offset Program) and the emission rights allocated to existing sources. Given that (1) an existing source's counterfactual emissions equal the emissions limit, which is not fully covered by the source's rights allocations, and (2) 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 the aggregate emissions limit and emission rights from existing sources. In other words, under this allocation and in the absence of trading, existing sources must reduce their emissions by $q_T - e_0$, while new sources must reduce all their emissions, that is, e_0.

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 control cost curve for the group of new sources (C'_N) is the right-hand axis. So drawn, the diagram displays all possible allocations of the total q_T units of emissions reductions between the two groups of sources. If the market is in long-run equilibrium, the clearing price of a frictionless market would be p^* and the cost-effective amounts of reduction 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., beyond the allowance allocation) from existing sources.

Suppose now that the total amount of actual trading is lower than the "cost-effective" volume, and is equal to $e_0 - (q_T - q^{\#})$, where $q^{\#} < q^*$.[30] The price that satisfies this new (imperfect) market equilibrium can be anywhere from p_1 to 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

[30] Note that, in theory, we cannot rule out the case in which the amount of trading exceeds q^*, but this case is a remote possibility, given the Offset Program's initial allocation of emission rights.

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 $e_0 - (q_T - q^\#)$.

Although we do not intend to estimate efficiency losses in this paper, it is still important to clarify, from a theoretical point of view, that if reductions from existing sources happen to equal $q^\#$, the efficiency losses are at least equal to area ACE, regardless of the observed price. Let us suppose that the new "equilibrium" price is $p^\#$ (shown in Figure 1 to be lower than p^*, though it could also be higher than p^*). Since at $p^\#$, all suppliers with marginal costs below $p^\#$ are willing to sell emission rights, the extreme possibility exists that the amount $e_0 - (q_T - q^\#)$ could be supplied along the marginal cost curve $\hat{C}'_E$, which does not include the lowest-cost emitters (distance BF = HG). Thus, efficiency losses for the pair $(q^\#, p^\#)$ relative to (q^*, p^*) can lie anywhere between area ACE and area 0HBCE.

We can now 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 the frictionless levels $[p^*, e_0 - (q_T - q^*)]$ deriving from the following numerical implementation.

5.2 *Numerical data and results*

Data for our four counterfactual emissions are displayed in 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 industry operators and sellers of control equipment.[31] TSP emissions can be abated not only by changing the maximum flow size F, but alternatively or additionally by installing end-of-pipe technology (e.g., filters, electrostatic precipitators, cyclones, and scrubbers) or by switching fuel (e.g., from wood, coal, or heavy oil to light oil, liquid gas, or natural gas).[32]

To understand the evolution of the program and the effect on it of natural gas, we split our analysis into two parts. Since industrial sources' first switches to natural gas

[31] We gathered data for a subsample of 255 existing sources and 49 new sources, then extrapolated from this for the whole sample.

[32] It is important to note that the effects of pre-emergency and emergency episodes on sources' marginal abatement costs are not included in this analysis.

occurred by the end of 1997, the first part of our analysis simulates a static “before-gas” market, using data from the 1997 database and assuming that natural gas was neither available nor expected to be. In the second part, we simulate a static “after-gas” market, using data from the 1999 database and taking into account the availability of natural gas and all long-lived abatement technologies already installed by 1997.

Table 4 summarizes counterfactual emissions capacities, capacity rights (DECR), and reduction requirements (q_T) for the before- and after-gas market simulations, followed by the frictionless market equilibrium results. Data shown in the table are for Counterfactuals #2 and 4. If we totally neglect the availability of natural gas, the “before-gas” market simulation indicates an equilibrium price between \$6,600 and \$12,600 and a large volume of trading, about 1,800 kg/day: roughly 45% of total DECR. With the price-based introduction of natural gas, the “after-gas” market simulation yields an equilibrium price of zero (because there are no reduction requirements at the aggregate level) accompanied by a still high volume of trading close to 30% of total DECR. Even if the price falls to zero, 333 sources—including 208 new ones—must cover their (counterfactual) emissions capacities with rights.

6. Market Performance: Practice

In this section, we examine whether actual prices and transaction volumes depart in any important way from those predicted by the above theoretical results. We also discuss possible explanations and offer recommendations.

6.1 Observed emission prices and transactions

Tables 5 and 6 display the prices and volumes of transactions, respectively, that we collected during the past two years from various sources. Before comparing these numbers to those predicted by the simulation models, we need to clarify two issues. First, all market transactions but one were of the “perpetuity trade” type. The only temporal trade took place in December 1996, to cover emissions capacity in one year.[33] Second, the trading activity reported in Table 5 corresponds to interfirm trading only (i.e., between unrelated firms);[34] the total volume without the one-year trade was 29.75 kg/day. Even without the many unreported quantities in Table 5, this number is much larger than the 3 kg/day volume of approved interfirm transactions reported in Table 6. This is because some transactions in Table 5 correspond to sales not directly involving an offset, while others correspond to transactions that are still under review by PROCEFF—clearly showing the length of time required for each offset approval.

While actual prices from December 1996 through 1997 do not depart significantly from prices predicted by the "before-gas" market simulation, the trading volume is only 9% of that expected when we include only the approved transactions (159.7/1844.9), and 18% of that expected for all transactions (337.1/1844.9). The introduction of natural gas has had an important effect on actual prices, but these are still high if counterfactuals are estimated to be below the emissions limit, as has been shown already in the "after-gas" market simulation. Market inefficiency would be further indicated if the volume of trading observed is still far below the model's prediction.

One might argue that the high price of rights and the low volume of trading are 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 existing sources' possession by tightening C_0 of expression (1) from 56 to 50 mg/m^3 during 2000-04, and to 32 mg/m^3 thereafter.[35] This implies that the total number of DECR in the market will drop the most, to 3,649.6 kg/day, during 2000-04, and to 2,335.7 kg/day thereafter. Despite the fact that a counterfactual higher than the 2005 limit could still support today's positive prices, the question remains: why has there been overcompliance well below limits already by 1997?

While some of the significant overcompliance might be an economic response to the probability that emergency and non-emergency episodes will occur, we argue below that several elements affecting market performance are responsible for the overcompliance

[33] We were told informally that this one-year-right was for an old plant that was required to cover emissions for one more year before being retired.
[34] Otherwise, there would be no price.
[35] It is unclear whether the limit will be tightened by taking into consideration all allocated rights or only those possessed by existing sources.

observed. It is important here to make clear that we are not arguing that the net benefits of overcompliance are necessarily negative (see, for example, Oates et al., 1989), but that overcompliance is symptomatic of market imperfection.

6.2 *From theory to practice*

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

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

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

In the case of DS 4, rights were allocated to all existing sources, implicitly recognizing the existence of historical rights. However, when such an initial allocation of emission –rights is made, the number of existing sources and their size must be known precisely. This was not the case with 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 on the quantification of sources and emissions; consequently, no offsets were authorized during the program's first three years.

Later—particularly after natural gas was introduced in late 1997—the authority came to realize that its initial allocation of rights was too generous. In efforts to reverse this situation, new sources registering after June 1998 were required to offset 120%, and new provisions are being added to the Decontamination Plan of Santiago reducing the number of existing rights in a way yet to be defined. All this regulatory uncertainty has been increased by recent expressed intentions from part of the authority to study the possibility of increasing offset requirements for new sources to 150%.

High transaction costs and lengthy, uncertain approval processes. Transaction costs are high because the procedures under which the system operates are far from simple; for this same reason, the approval process is also uncertain. Table 6 offers two pieces of evidence: the volume of intra-firm trading is much larger than the volume of inter-firm trading, and a large number of transactions are still under review. Also, the high transaction costs mentioned result from substantial searching, given that no formal market exists for these emission rights.

Poor enforcement. Because of limited resources, enforcement of the program has always been very weak. During the early years, enforcement problems occurred 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 the enforcement challenges of reconciling rights and emissions have remained: note, in Table 6, the difference between the total volume of trading (337.1 kg/day) and the total rights required from new sources (427.6 kg/day).[36]

Market power. Another critical feature of the scheme under analysis is the high concentration of rights that has occurred. Grouping sources according to ownership using the Internal Revenue Service Number reported in the register shows that 21 firms (as distinct from sources) own 50% of the total rights; five firms own 31% of all rights. The market thus has a degree of concentration that could explain, in part, the lower supply of rights and their high price (Hahn, 1983).

Thin market. One reason for the currently thin market is that potential sellers are unwilling to sell because of uncertainties that they will be able to buy back capacity rights

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

later, if needed, to expand existing sources or install new ones. A second reason involves monitoring constraints: because it is impossible to monitor TSP emissions daily, 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 prices closer to their reservation prices: prices higher than would ordinarily be considered competitive. This scenario is entirely consistent with what is being observed in the Offset Program: firms are paying high prices despite excess supply at the aggregate level.

It seems that the authority did not sufficiently attend to providing basic institutions that would enable the market to take off and develop, like annual auctions and a more liquid currency. Annual auctions help to start up a market by sending important price signals and giving new sources access to emission rights. In an effort to see more “one-year rights” like that listed in **Table 5,** the authority should develop a more liquid currency such as a daily capacity right lasting only one year without the possibility of banking. Given the monitoring limitations inherent in annual measurements, such an instrument would neither compromise the environmental goals of DS 4, nor impose any extra burden on the regulator.

Limited program scope. The question of which sources are permitted to enter the system becomes particularly relevant when one considers that industrial processes, which account for more than 50% of particulates originating from stationary sources, have been left out of the system. On the one hand, this exclusion creates additional market uncertainty because at some future point, these sources may become affected and enter the market as 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 an active, competitive market for emission rights, more sources of particulate matter that are currently regulated or are about to be regulated under some command-and-control approach should be included in the system, starting with industrial processes. It may even be necessary to plan how to include in the system those mobile sources that are heavy emitters of PM10, especially diesel-powered buses.

5. Conclusions

Recent years have seen widespread interest in the use of market-based instruments—particularly emissions-trading—to deal with air pollution, rather than the traditional command-and-control approach of setting emission and technology standards. This paper has evaluated the "Emission-Offsets Trading Program" established by Supreme Decree No. 4 (DS 4) in March 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, however, our results indicate that the market created under the program has performed poorly due to regulatory uncertainty, high transaction costs, lengthy and uncertain approval processes, and inadequate enforcement. It is unfortunate that in its pursuit of progress toward attaining ambient quality standards, the environmental authority paid insufficient attention to setting up conditions for helping the market to develop. However, 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 complete its inventory of sources and emissions more quickly.

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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	7,290	20.6	7,482	31.0
TOTAL	35,389	100.0	24,104	100.0

For data on suspended dust from paved and unpaved roads, see text.
Source: CONAMA (1997a).

Table 2. Summary statistics for affected sources: 1993–99.

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
Maximum flow (F) (m^3/h)						
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 (C) (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
Noncompliants	106	87	83	29	0	0
Natural gas users	0	0	0	0	145	179
Capacities and rights (kg/day)						
DEC	7,442.5	6,500.2	5,195.1	3,535.0	1,953.6	1,636.6
DEC w/natural gas	7,442.5	6,500.2	5,195.1	3,535.0	1,742.4	1,380.3
DECR	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: Elaborated from PROCEFF.

Table 3. Summary statistics for unaffected sources: 1993–99.

Variable	1993	1997	1998	1999
No. of sources	1616	1856	1963	1989
Flow (F) (m^3/h)				
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 (C) (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 DECR (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 transaction volumes for interfirm trades completed by July 1999.

Date	Price (1998US$)	Volume (kg/day)	Transaction type
Dec-96	16,558	N.A.	permanent right
Dec-96	17,031	N.A.	permanent right
Dec-96	14,193	0.9	one-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 represents the sale of a one-year right at $1,419 that we converted 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 DECR allocated	401	3,981.3
Approved offsets	32	159.7
Internal (intrafirm) offsets	30	156.7
External (interfirm) offsets	2	3.0
Internal and external offsets under review	27	104.5
Sales not involving an offset	10	72.9
Total trading activity	69	337.1
Offsets required from new sources by 1999	208	427.6

Source: Elaborated from data provided by PROCEFF.

Figure 1. Market Equilibrium.