Temporal Hotspots in Emission Trading Programs:

Evidence From The Ozone Transport Commission's NO_X Budget

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Introduction

The use of Market Mechanisms and Incentives (MM&I) for environmental protection has increased over the last several years, and proposals for new MM&I policies are increasing. Notable (perhaps even principal) among these proposals are cap-and-trade (C/T) systems, which as the name implies, create a permanent limit on total emissions yet provide firms with flexibility in compliance. Several concerns have been raised about the environmental and economic outcomes of C/T systems, in particular about the potential for "hot spots" and about the viability of markets in emission allowances. Environmentalists are concerned that C/T systems may allow for localized pollution problems while industry is concerned that there be a large, stable enough market in allowances so that they can count on being able to buy or sell allowances at reasonable and predictable prices (Dudek and Goffman 1992; Solomon and Rose 1992; Campbell and Holmes 1993; Chinn 1999). The results so far have been mixed on both counts, some emission trading programs have had problems with hot spots and environmental justice issues and others have not (Drury 1999; Swift 2001). Similarly, some emission allowance markets have been successful and others have not (Foster and Hahn 1995; Carlson *et al.* 2000; Israels *et al.* 2002).

This paper examines several key aspects of an early multi-state C/T system designed to control oxides of nitrogen (NO_X) in nine Northeastern States, the Ozone Transport Commission's (OTC) NO_X Budget. Several earlier papers have examined the political economy of the OTC NO_X Budget (Farrell 2001; Farrell and Morgan 2003). Electricity generating plants, including co-generators, dominate regulated facilities in the OTC NO_X Budget (representing more than 90% of seasonal NO_X emissions) and will have a key role in the upcoming NO_X SIP Call, so this paper focuses on the electric power sector (U.S. Environmental Protection Agency 1998).

The OTC NO_X Budget is a cap-and-trade (C/T) system[1] operated jointly by the nine states shown in green in Figure 1: CT, DE, MD, MA, NH, NJ, NY, PA, RI, plus the District of Columbia. Three states in the OTC chose not to participate in the NO_X Budget Program (ME, VA, VT), shown in yellow. Maryland did not participate in 1999 due to a lawsuit. The NO_x Budget applies to electrical generating units 25 megawatts or larger and similar-sized industrial facilities (such as process boilers and refineries), and covers a 5-month control period from May through September. The NO_x budget has uses a C/T system to reduce emissions by 55-65 percent for 1999–2002 and 65-75 percent starting in 2003.

The OTC NO_x Budget has some important and distinctive features. First, there were no early auctions or other methods for price discovery before the year it actually went into effect, and no method to build up a bank of allowances before the start of the program. These have proved important in other markets (Ellerman *et al.* 2000 pp. 161-5, 174-6). Second, the NO_X Budget is operative only during the 'ozone season' of May through June. Third, and most unusually, banked allowances can be discounted through provisions called 'progressive flow control' (PFC). Under these rules, several months after the true-up date for the relevant control period, regulators determine the discount factor for all banked allowances for the upcoming year. Although a relatively straightforward formula is used to determine the discount factor, it is based

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[1] This paper assumes the reader has a general familiarity with MM&I policies. For a more detailed description of emission trading programs, see Farrell, A. E. (2003). Clean Air Markets. In Encyclopedia of Energy. C. Clevelenad, Ed.: Academic Press. pp. forthcoming..

on aggregate behavior of all firms that hold allowances, so individual firms do not know what (if any) discount will be applied to their allowances until after they have made decisions about banking allowances. This adds an element of uncertainty to the allowance market.

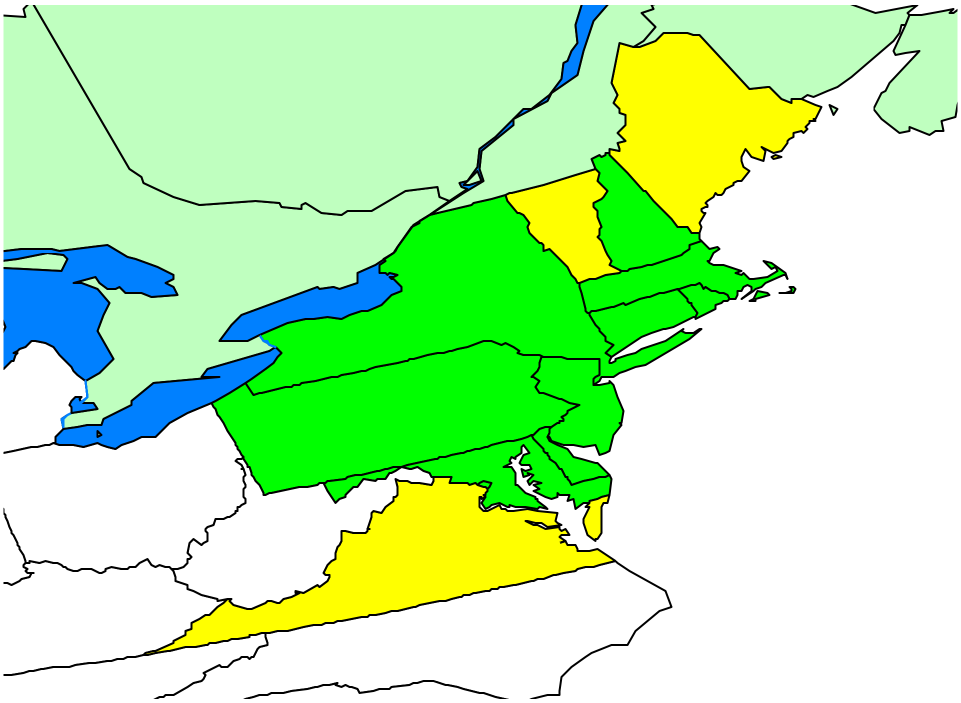

Figure 1: Sates in the Ozone Transport Region.
Green: States in the OTC NO_X Budget Program.
Yellow: States not the NO_X Budget Program

The intent of PFC is to deal with the episodic nature of photochemical smog (commonly measured in terms of ozone concentrations) in the northeastern United States (Possiel and Cox 1993). Smog is a secondary pollutant, formed from precursor compounds, of which NO_X is the most important in the OTC region (Milford *et al.* 1994). Unhealthful smog levels occur in the OTC region on only a limited number of days (usually <20 per year), which occur when meteorological conditions are most favorable for smog formation and accumulation. These are typically hot summer days when anthropogenic NO_X emissions also tend to rise as electric power plants increase generation to meet air conditioning demand. PFC was implemented to limit the use of banked allowances out of concern that if one or two cool summers was followed by a hot summer, firms would build up a significant number of allowances that could allow them to emit more NO_X than the capped level, possibly allowing firms to comply with the requirements of the program without achieving its goals.

However, it is not clear that progressive flow control adequately addresses this problem of a mismatch between the time period of the environmental problem (2-5 day episodes) and the control period (5 months). Even small differences may be important because ozone concentrations are highly non-linear functions of local NO_X concentrations. This is potential problem may be exacerbated by the fact that power plant operation and several NO_X control technologies can be easily adjusted in near real-time and because restructuring has led to higher power prices when demand is greatest (Zhou *et al.* 2001; Blumsack *et al.* 2002).

NO_X control technologies can be divided into three rough categories: combustion controls, selective catalytic reduction (SCR) and non-selective catalytic reduction (SNCR). Combustion controls (e.g. low-NO_X burners, overfire air, etc.) are used to change the shape, temperature profile and air/fuel ratio of the flames in the boiler in order to minimize the amount of fuel and atmospheric nitrogen (NO_2) that is oxidized. The other two technologies are used to chemically reduce NO_X into molecular nitrogen (N_2) and water (H_2O) by spraying a nitrogen-based chemical reagent, usually urea (CH_4N_2O) or ammonia (NH_3) into the flue gas.

In the case of SNCR, reagent is introduced close to the boiler because the greatest NO_X reduction is achieved at temperatures between1, 600-2,200°F. Multiple injection locations may be required to permit adequate control during partial load conditions. Typical SNCR technologies can lower NO_X emissions 30-50% from coal-fired power plants, although more recent advances may give better performance. The capital costs for SNCR units are about 10-20$/kW for retrofits and half that for new construction, the difference being the need to modify boilers and flues in during a retrofit. Operating costs associated with reagent, maintenance and power requirements usually amount to 1-2$/MWh.

SCR controls are very similar, except that they contain beds of catalyst, usually made of a vanadium/titanium formulation (V_2O_5 stabilized in a TiO_2 base) and zeolite materials. The flue gas flows around and through these catalyst beds, speeding up the reduction reactions and allowing for much lower temperatures, 650-720°F. SCR technologies can lower NO_X emissions 70-95% from coal-fired power plants. The capital costs for SCR units are about 50-150$/kW for retrofits and less for new construction, although very unit-specific difficulties in fitting an SCR unit into (or next to, or on top of) an existing power plant can drive those costs up. Operating costs associated with reagent, catalyst cost, maintenance and power requirements usually amount to 4-8$/kWh, largely dependent on the catalyst's life.

Two important potential are problems associated with SCR and SNCR controls. The first is the buildup of ammonium bisulfate on the pre-heater or other downstream components. These buildups can reduce plant efficiency and may require maintenance to remove them. The second problem is that ammonia may contaminate the fly ash, which may make it difficult or unsafe to handle and thus hard to sell to concrete makers or other buyers. Thus, careful, controlled operation of these technologies is required to maximize plant operation and revenue.

Under these conditions, power plant operators may respond to economic incentives in the both the production of electric power and the management of NO_X emissions, possibly turning NO_X controls down when electricity prices are highest in order to increase electricity production (and therefore revenue), or possibly shifting from one plant to another as fuel prices change, thus changing the rate and mass of NO_X emissions during hot summer days. Such actions could lead to higher levels of air pollution than would be expected under a command-and-control approach, and raises the question of whether the periodicity of the NO_X Budget gives firms too much temporal flexibility even with progressive flow control (Farrell *et al.* 1999).

Concern about spatial hotspots is more common than about temporal hotspots. Here the question is: Does emission trading result in a geographic pattern of emissions that is undesirable, even if total mass emissions are limited by a cap? This concern is sometimes associated with the term 'wrong-way trades', suggesting that an emission trade may in effect move pollution from a relatively clean area to a relatively dirtier area. This concern also forms the basis of environmental justice claims of disparate impacts on minority communities.

Concerns about these temporal and spatial effects have been an important part of the policy landscape. For instance, the RECLAIM program had two trading zones as well as a policy that did not allow banking from one year to another, features that addressed each of these issues (Fromm and Hansjurgens 1996). Some local emission reduction credit programs feature sunset provisions for credits. The debate about the Clean Air Act's Acid Rain Program for SO_2 featured a spatial limitation almost to the end and the current Clear Skies Initiative features spatial limitations (Nash and Revesz 2001 pp. 589-593; Bush 2002). Some experts feel this is an inherent problem of C/T systems and several solutions have been proposed, including trading zones, markets in units of environmental degradation or health impacts, offset ratios in emissions markets, and a web-based analysis for quick pre-approval of proposed emission trades (Atkinson and Tietenberg 1987; Raufer 1998; Nash and Revesz 2001). Others who have looked at such restrictions are skeptical (Bernstein *et al.* 1994; Stavins 1997).

Several studies on the potential existence and importance of hot spots have been conducted. Some simulation-based analyses so far of the Acid Rain SO_2 program have shown benefits from trading (Burtraw and Mansur 1999). Simulations of NO_X emission trading systems in the eastern part of the United States and in California showed no significant effect due to directionality (i.e. no significant net 'wrong way' trades and no significant hot spots), but that limiting trading to avoid even the potential problems imposed a cost increase for a C/T system of several percent (Johnson and Pekelney 1996; Dorris *et al.* 1999). Several simulations by Nobel and others of NO_X C/T system in the Houston-Galveston area have shown that spatial and temporal variability can produce only small changes in outcomes, compared to the average benefit, and that these changes may be slight improvements (Nobel *et al.* 2001; Nobel *et al.* 2002). However, these studies have all been simulations of one sort or another. One of the goals of this paper is to examine data based on the actual outcomes of a C/T system to gain insights into the potential for hot spots to be a problem in practice.

The overall effects of the NO_X Budget Program are described in the Environmental Protection Agency's (EPA) annual compliance reports for the OTC NO_X Budget program, which provide aggregate results, including the number of units regulated, ozone season emissions and allowance allocations (by state and total), the number of banked allowances (total), noncompliance issues and the progressive flow control ratios.[2] This analysis goes somewhat deeper by examining data at a much more fine level of temporal detail (hourly).

Data and Methods

Qualitative data used in this study was gathered from interviews with participants in the NO_X Budget Program, including regulators, managers in regulated firms, and brokers. Electric power plant and other plant configuration information were compiled from several sources, including EPA's *E-GRID* database, several EIA reports and publicly available material provided by firms with facilities regulated by the NO_X Budget. Unit-specific, hourly NO_X emissions data for all sources in the OTC NO_X Budget for 1998-2001 were obtained from Resource Data International (RDI). Weekly NO_X allowance prices were obtained from several brokers and industry trade publications, especially *Air Daily*, for 1998-2003. Hourly electricity data (demand, generation,

2 http://www.epa.gov/airmarkets/cmprpt/index.html

imports, and prices) were obtained from the Independent System Operators (ISO) for the New England (NE), New York (NY), and Pennsylvania-New Jersey-Maryland (PJM) interconnects. Fuel prices were obtained from RDI and the New York Mercantile Exchange.[3]

Insights from the interviews and literature review were used to guide the several quantitative analyses that followed. There are 907 'sources' in the OTC NO_X Budget Program, which, in 2000 had emissions of 952,049,548 lbs. This study focused on 'large' (>100MW_e) electric power plants and co-generators, which accounted for 773,530,680 emissions in 2000, or 81% of all regulated emissions. This data set contained 476 units combined in 137 plants. A part of this analysis considered only power plants and not co-generators and part considered only plants in PJM, due to data availability. Data from 1998-2000 was used. Table 1 shows some of the details of large power plants in the OTC states and post-combustion NO_X controls.

Table 1: Large (>100MW) power plants (not co-generators) in the OTC States

	Number of Units	Capacity (MW)	Post-Combustion NO_X Controls (2002)	
			SCR	SNCR
CT	26	3767	1	2
DC	2	550	-	-
DE	13	2149	--	1
MA	27	6891	3	1
MD	48	8386	2	1
NH	9	1034	2	-
NJ	67	8157	2	2
NY	153	16519	4	-
PA	64	15962	3	-
RI	6	1127	4	-
Total	415	64542	21	7

The first quantitative analysis compared key values in terms of emissions and emissions rates for various periods. Because power plant emissions are closely associated with generation, comparisons to control for the effect of changes in demand were made. In addition, because emissions during ozone periods are of greatest importance in terms of human health, these periods were identified and compared as well. The second quantitative analysis consisted of a series of Ordinary Least Squares (OLS) regressions designed to more rigorously investigate possible reasons for observed changes in NO_X emissions during the course of the year. Again, greatest focus was given to the periods during which NO_X emissions have the greatest potential impact on human health – ozone episodes.

[3] Relevant URLs include: http://www.epa.gov/airmarkets/egrid/, http://www.eia.doe.gov/fuelelectric.html, http://www.emissions.org/, http://www.energyargus.com/, http://www.epa.gov/airmarkets/tracking, http://www.iso-ne.com/, http://www.nyiso.com/, and http://www.pjm.com/

Results

The interviews with the participants in the OTC NO_X Budget Program indicated a wide variety of opinion. The early years of this market (1997-2000) occurred in a very different world – this was while the dot.com stock market bubble and electricity industry restructuring were underway, and before the financial scandals associated with Enron and some electric power markets. A key finding of this study was that virtually every firm with a requirement to reduce emissions took a conservative approach to the trading of emissions allowances. They traded relatively infrequently and generally did not rely on the market very much for compliance.

Reluctance to rely on the NO_X Allowance market came from several sources. Perhaps most importantly, market participants perceived very large uncertainties in the market, especially over the ability to purchase allowances. The relatively small number of potential participants in the NO_X market and, over time, the observation that relatively few transactions occurred during most weeks, meant both buyers and sellers were concerned that their own participation in the market could change market prices, generally in an unfavorable direction. The slow pace of the allowance market may have been enhanced by a somewhat hurried start of the program in 1999 and the lack of mechanisms for early price discovery, such as allowance auctions (Farrell 2000). Uncertainties were also introduced by the PFC provisions, and lawsuits (especially in Maryland) in 1998-99.

Another reason for reluctance to rely on the market was that most firms thought of the NO_X Budget program as a regulatory issue for which the most appropriate concept is compliance, rather than a market opportunity for which the most appropriate concept would be profitability. The relatively low cost of the program relative to electricity markets at the time may also have contributed. For instance, using average values for the 2000 ozone season, NO_X emission allowances were priced at 0.40$/MWh, while electricity prices averaged 42$/MWh and peaked at over 1,500$/MW in at least one market. Given these incentives, it is likely that power plant operators would focus on reliability in generating electricity over making slight changes to the emissions control equipment to optimize NO_X control costs. The structure of contracts in electricity markets would tend to reinforce this effect, since they punish both over- and under-generation relative to the amount promised in day-ahead markets. Interviews with market participants and power plant operators supported these arguments. Thus, many firms with regulated sources participated in the NO_X market only occasionally, whenever their total environmental compliance plan was modified, which might happen only once or twice per year.

An exception to this observation of low participation can be found in speculators in the NO_X Allowance Market, including Enron, Arizona Power System, and individual trading desks at some regulated firms. Speculative activities were not uncommon in the first few years of the market but became more rare after 2001, as many markets slowed down.

The results of the first set of quantitative analyses are discussed next. Table 2 shows a variety of emissions values as well as generation for the ozone seasons (May-September) in 1998-2001. This information is shown in graphical form in Figure 2. The data has been normalized in the tables to allow all the relevant values to be shown on the same figure. Total emissions over the NO_X season (tons) declines in each year, and declines substantially (by almost 25%) in the first year of the program from the pervious year. Similarly, the average emission rate (lb/hr) declines every year. However, the peak emission rate recorded over any single hour during the ozone season at first declines by about 15% from 1998 to 1999 and then rises again, although never rising higher than pre-program levels. The peak emission rate may be a better indicator of the impact of the OTC NO_X Budget program than the seasonal values because of the episodic nature of the ozone problem. This suggests that there may be a problem with temporal hotspots. However, it should be noted that even the 1998 emissions were lower than the baseline used for the OTC NO_X Budget program, which was 1990. In addition, it is hard to know what the counter-factual condition would be (i.e. if there was no NO_X Budget, what regulatory program would exist?) and what the resulting emissions profile would be.

Table 2: Ozone Season NO_X emissions and generation

Year	Emissions (tons)	Avg. NO_X rate (lb./hr)	Peak NO_X rate (lb./hr)	Avg. NO_X rate (lb./MWh)	Peak NO_X rate (lb./MWh)	Generation (GWh)
1998	156,484	83,310	134,947	2.9	20.0	108,799
1999	120,048	63,082	115,628	2.1	8.2	118,107
2000	117,025	60,640	124,125	1.2	5.5	134,390
2001	111,043	57,223	126,556	1.1	3.0	131,521

Note: These data are for all power plants, including those in Maryland that only participated in the 2000 and 2001 NO_X Budget program.

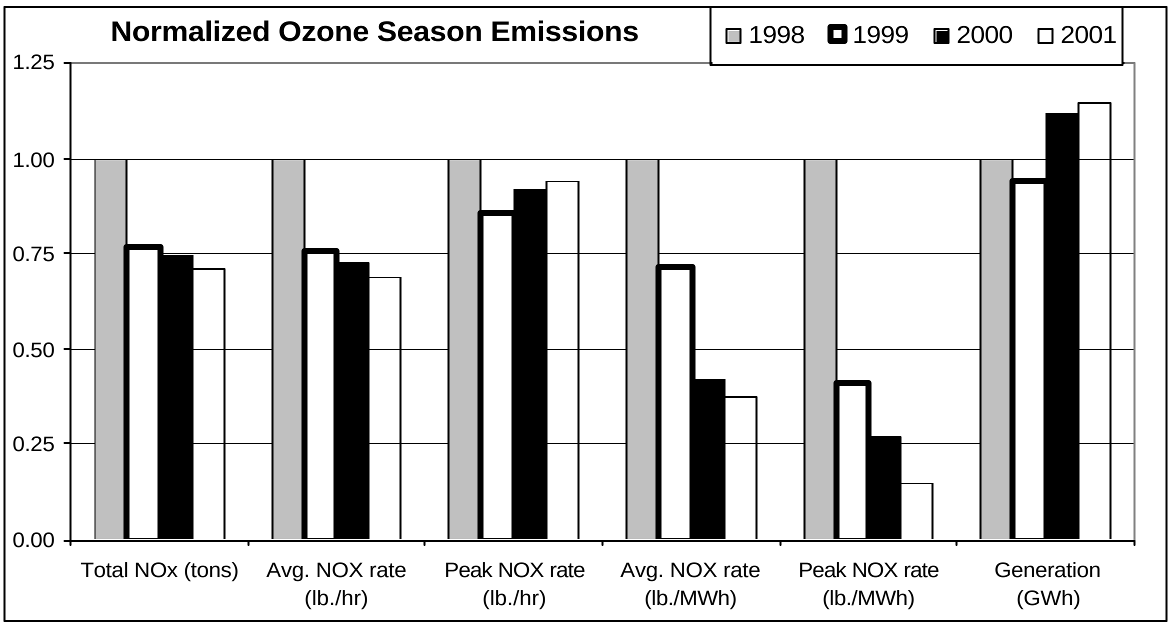

Figure 2: Normalized Emissions during the ozone season

Also significant are the very substantial declines in emissions per unit of output (lb./MWh, or emission factor), which is a result of both declining emissions and rising generation. This analysis shows that the large (>100MW) power plants in the OTC NO_X Budget controlled emissions, on aggregate, more each of the first three years of the program. Similar but less strong trends are seen in annual emissions data (not shown here).

Table 3 and Figure 3 present emissions and generation for the worst ozone episode in each year, as measured in New York City (which is roughly in the center of the OTC states). Peak ozone concentrations ranged from 0.142-0.171 parts per million (ppm), compared to the health standard of 0.120ppm. Two episodes lasted three days (2000 and 2001), and two lasted four days (1998 and 1999), making the total tons and total generation results less easily comparable.

Table 3: Ozone episode NO_X emissions and generation

Year	Emissions (tons)	Avg. NO_X rate (lb./hr)	Peak NO_X rate (lb./hr)	Avg. NO_X rate (lb./MWh)	Peak NO_X rate (lb./MWh)	Generation (GWh)
1998	5,670	91,996	121,570	3.0	4.9	3,374
1999	4,238	85,038	110,573	2.8	5.5	2,980
2000	2,483	65,658	83,643	1.2	1.7	2,135
2001	3,801	100,976	126,556	1.8	3.0	3,177

Notes: These data are for the worst ozone episode in each year, which were of different lengths.

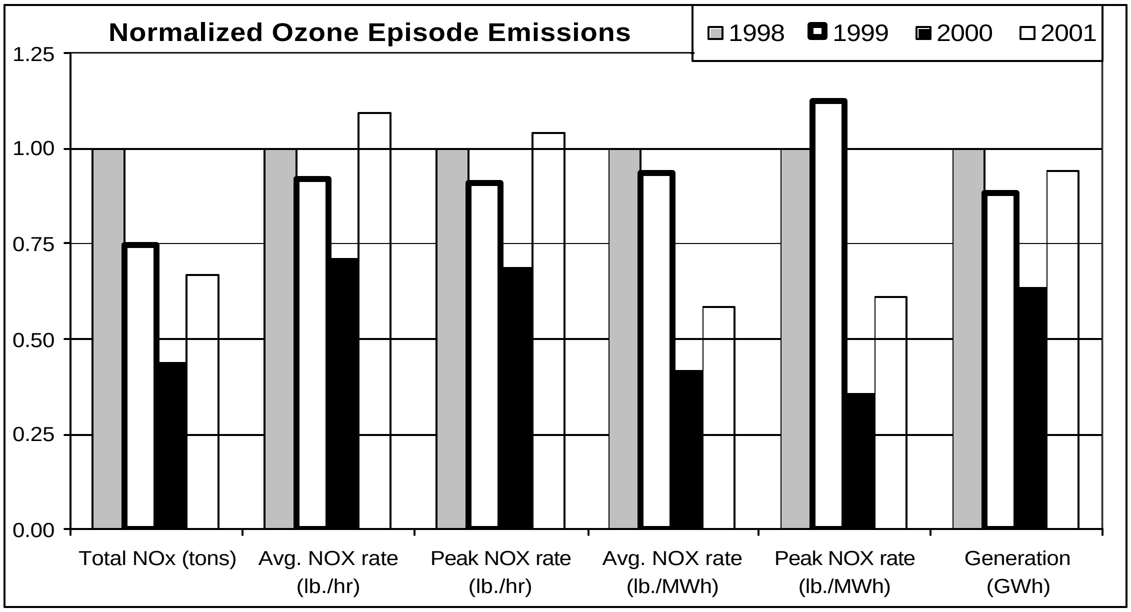

Figure 3: Emissions and generation for the worst ozone episodes in four years

As with the ozone season analysis, total emissions during ozone episodes periods decreased with the NO_X Budget, but they have not declined each year since 1998. However, the average and peak NO_X emission rates (lb/hr) are highest in 2001, while the peak emission factor (lb/MWh) is highest in 1998. More tellingly, average generation (in MW, not shown) during these episodes is considerably (12%-80%) higher than during the ozone season as a whole. Further, comparing between Tables 1 and 2, it can be seen that the absolute magnitudes of the average NO_X emission rates (lb/hr) are substantially (8% to 77%) higher during the ozone episodes than during the entire ozone season they occur in. Thus, temporal hotspots do occur under the OTC NO_X Budget program, however it is not yet clear if this is due to the C/T system.

One reason for the high emission rate in 2001 is that electricity demand for this period (8/7-8/9) was extremely high. Total generation for these three days was greater than that for the four-day long ozone episode of 1998 (3.18GWh compared to 2.98 GWh), while peak generation was even more exceptional (52GW compared to 37-39GW for the other three episodes). At the same time, the 2001 ozone episode was the least severe, with a peak concentration of 0.142ppm.

This analysis suggests two things. First, NO_X emissions under a C/T system are strongly correlated with electricity generation. This is particularly important because the same is true of traditional command-and-control regulation, the most reasonable counter-factual regulatory situation. Second power plant NO_X emissions in the Northeast are not always determinative of the level of smog problems in the area. This may be important because it suggests that even if there is a temporal hotspot problem for all seasonal NO_X C/T trade systems designed to combat regional photochemical smog, relatively modest-sized hotspots may not matter.

While an increase in emission rates due to increased electricity demand (and thus increased generation) would occur under both C/T and traditional command-and-control regulation, it may still be the case that plants take advantage of the temporal flexibility and change their operations during ozone episodes or other periods (such as when electric power prices are higher. Aggregate comparisons here are difficult in particular because to a significant degree, NO_X emissions depend on which specific power generators are operating at any give time. One approach would be to look at periods with similar total power generation, when the units operating would be roughly similar.

This approach is taken with Table 4 and Figure 4, which present data for four three-day periods with generation close to the three-day period containing the worst ozone episode in 2000 (00e). The first two are also taken from 2000, one period during the ozone season (00s) and one period is not during the ozone season (00n). The second two are from the ozone seasons in 1999 and 2001 (99 and 01, respectively). While not a perfect control, this should reduce the differences due to having different generators running for any given period, assuming dispatch order does not change appreciably.

Table 4: Emissions and generation for periods comparable to a 2000 ozone episode

Period	Emissions (tons)	Avg. NO_X rate (lb./hr)	Peak NO_X rate (lb./hr)	Avg. NO_X rate (lb./MWh)	Peak NO_X rate (lb./MWh)	Generation (GWh)
00e	2,483	65,658	83,643	1.2	1.7	2,135
00s	2,236	59,217	87,471	1.2	1.4	1,916
00n	3,613	95,527	113,253	2.6	3.6	2,315
99s	2,766	74,117	101,968	2.6	3.2	1,880
01s	2,008	52,917	82,768	1.1	1.6	1,820

Note: Table contains data for four three-day periods with total generation close to the worst ozone episode in 2000, 6/9-6/11, labeled 00e. Period 00s occurred during the 2000 ozone season. Period 00n occurred during 2000 but not during the ozone season. Period 99s and 01s occurred during the 1999 and 2001 ozone seasons.

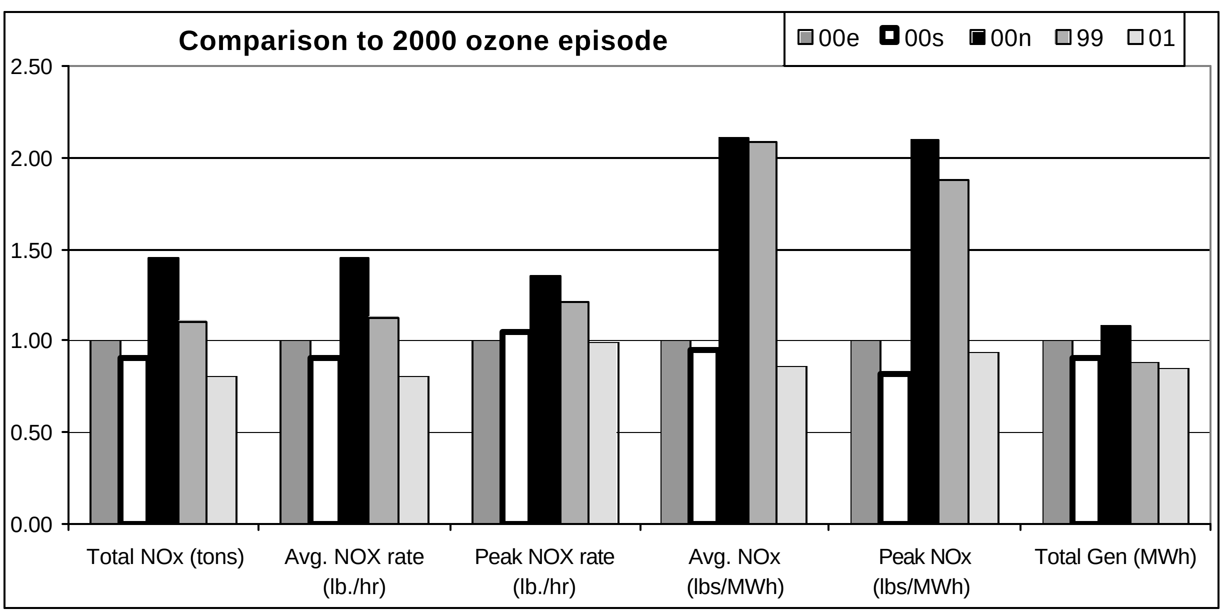

Figure 4: Emissions and generation for periods comparable to a 2000 ozone episode

Emissions in the non-ozone season comparison period (00n) are substantially higher than those, during the season, which is expected. Differences in terms of the emission factor (lb/MWh) are greatest, which is important because this metric reflects changes in dispatch and plant operation and is independent of amount of electricity generated. The emissions of the other two comparison periods (00s and 01s) suggest, on the contrary, very similar dispatch and plant operation. This suggests that the NO_X Budget Program does not tend to change the propensity for temporal hotspots. To test this definitely, however, a more rigorous approach is needed.

A set of OLS regression models were developed to test for the effect of the OTC NO_X Budget program on temporal hotspots by looking for evidence of changes in the behavior of large (>100MW) power plants. Data for 2000 was used. This analysis proceeded in three steps.

First, several models were estimated using data for all the large plants in the OTC region. The second step consisted of using the same models with data from large plants in PJM and specifying additional models were specified with variables for electricity prices, which were available for the entire year only for PJM. Power plants in the PJM interconnect account for a majority of electricity capacity in the entire OTC region (55%), so these results are reasonably representative of the overall outcomes.

The results from the first two steps are presented in Tables 5 and 6 below. The models are specified to use generation, fuel prices, electricity prices, and the OTC NO_X Budget to explain hourly ozone emissions. Various specifications were used; those shown here demonstrate the results best. All of the coefficients are significant at the 0.001 level, and all have the expected sign, save two minor exceptions.

Model 1 consists only of a variable for electricity generation at power plants (excluding co-generators for the OTC data) and a constant. Even this simple model achieves high explanatory power (R^2 values of 0.64 for the OTC and 0.78 for PJM). This confirms the earlier assumption that electricity generation would be a good predictor for emissions. Model 2 adds a dummy variable that takes a value of one for hours during the ozone season and a value of zero otherwise. The predictive power of these models is significantly stronger (R^2 values of 0.84 for the OTC and 0.96 for PJM). These results strongly suggest that the OTC NO_X Budget has had a very strong affect on emissions from large power plants, which is unsurprising.

More importantly, models 3-6 add fuel and electricity prices (and co-generators for the OTC data) to models 1 and 2. While the coefficients for these specifications are significant, and they improve the predictive power of the regression models without the ozone season dummy variable (models 3 and 5), they have very little or no effect with the dummy *is* in the model (models 4 and 6). This strongly suggests that fuel and electricity prices have little or no effect on NO_X emissions of large power plants in the OTC NO_X Budget program relative to the requirements of the program itself. Very similar results are obtained with a variety of specifications and when allowance prices are included.

Table 5: Regression models for large OTC plants for all of 2000

Model 1-OTC					
Variable	Coefficient	*t* – statistic	*p* – value		
POWERGEN	3.10	175	0	N	8,760
Constant	5,100	13	0	R^2	0.78
				Adj. R^2	0.78

Model 2-OTC					
Variable	Coefficient	*t* – statistic	*p* – value		
POWERGEN	3.37	373	0	N	8,760
D_SEASON	-16,600	-162	0	R^2	0.94
Constant	6,400	34	0	Adj. R^2	0.94

Model 3-OTC					
Variable	Coefficient	*t* – statistic	*p* – value		
POWERGEN	2.94	234	0	N	8,760
COGEN	3.79	66.0	0	R^2	0.90
COALPRICE	192,000	29.6	0	Adj. R^2	0.90
GASPRICE	-5050	-18.0	0		
Constant	-243,000	-27.0	0		

Model 4-OTC					
Variable	Coefficient	*t* – statistic	*p* – value		
POWERGEN	3.33	381	0	N	8,760
COGEN	-.427	-8.05	0	R^2	0.96
COALPRICE	104,000	24.5	0	Adj. R^2	0.96
GASPRICE	-1,870	-10.3	0		
D_SEASON	-16,900	-111	0		
Constant	-35,200	-9.36	0		

Table 6: Regression models for large PJM plants for all of 2000

Model 1-PJM					
Variable	Coefficient	*t* – statistic	*p* – value		
POWERGEN	3.00	125	0	N	8,760
Constant	-27,800	-40	0	R^2	0.64
				Adj. R^2	0.64

Model 2-PJM					
Variable	Coefficient	*t* – statistic	*p* – value		
POWERGEN	3.24	200	0	N	8,760
D_SEASON	-14,400	-104	0	R^2	0.84
Constant	-287,00	-61	0	Adj. R^2	0.84

Model 5-PJM					
Variable	Coefficient	*t* – statistic	*p* – value		
POWERGEN	3.07	108	0	N	8,760
ELECTPRICE	-16.3	-4.2	0	R^2	0.64
Constant	-29,200	-37.9	0	Adj. R^2	0.64

Model 6-PJM					
Variable	Coefficient	*t* – statistic	*p* – value		
POWERGEN	3.18	167	0	N	8,760
ELECTPRICE	15.6	5.98	0	R^2	0.84
D_SEASON	-14,500	-104	0	Adj. R^2	0.84
Constant	-27,400	-53	0		

The third step in the regression analysis applied model 3 to data from the worst ozone episode in 2000 and two other periods in that year of the same duration with very similar total electricity generation, one during the ozone season and one not during the ozone season. . This analysis parallels the analysis above associated with Table 4 and Figure 4. The key regression results are presented below in Table 7. The R^2 values for these models are extremely high, but the sign and significance of most of the variables change from one model to another. Only the coefficient for electricity generation is significant and has the expected sign in all three models. This suggests that generation can be an extremely good predictor of NO_X emissions over short periods of time, and that some of the residuals in other (annual) models applied to annual data may be associated with the operation of different power plants over the course of the year due to scheduled (and unscheduled) maintenance. If it is assumed that within each of the three-day periods that the same power plants are operated, the results in Table 7 indicate extremely stable operation. The idea that power plant operators might change plant operation as electricity prices change over the course of the day (power prices often have a diurnal pattern) is not supported by this analysis.

Interesting but less obvious are the values taken by the generation coefficient in the three models shown in Table 7. For comparison, the coefficient found using annual data is 2.94 (see Table 5). The coefficient for the ozone episode (00c) is lower, while the coefficient for the in-season comparison (00d) is close to the annual value and the coefficient for the non-season (00e) value is higher. (The coefficient for generation when model 3 is applied to October-December data is similar to the non-season value.) A higher value for the non-season coefficient is expected since this implies that power plants in the OTC produce more NO_X when the NO_X Budget program is not in force, which was observed in models 2, 4, and 6. However, it is not so clear why the value for the ozone episode itself should be so low. Investigating more ozone season comparisons or using a disaggregated analysis may be needed to resolve this issue.

Nonetheless, this third step of the regression analysis provides no support for the idea that the NO_X Budget program has led to increased emissions during ozone episodes, undercutting concerns about temporal hotspots.

Table 7: Regression models for large PJM plants for 2000

Model 3-00e: ozone episode

Variable	Coefficient	*t* – statistic	*p* – value		
POWERGEN	2.27	12.6	0	N	72
COGEN	2.71	1.94	0.057	R^2	0.98
COALPRICE	-12,800	-0.877	0.384	Adj. R^2	0.98
GASPRICE	-205	-0.230	0.818		
Constant	213,000	38.7	0.228		

Model 3-00s: comparison during ozone season

Variable	Coefficient	*t* – statistic	*p* – value		
POWERGEN	3.01	19.1	0	N	72
COGEN	1.74	1.47	0.240	R^2	0.99
COALPRICE	37,900	4.30	0.0001	Adj. R^2	0.99
GASPRICE	114	4.59	0		
Constant	-517,000	-4.37	0		

Model 3-00n: comparison not in the ozone season

Variable	Coefficient	*t* – statistic	*p* – value		
POWERGEN	4.02	23.6	0	N	72
COGEN	-2.81	-2.82	0.0062	R^2	0.96
COALPRICE	-2,830	-0.208	0.836	Adj. R^2	0.96
GASPRICE	41.4	0.195	0.846		
Constant	58,100	0.339	0.736		

Discussion

The analysis presented here supports the idea that temporal variations in NO_X emissions occur during the ozone season in the Northeast, with higher than average emissions occurring during ozone episodes. However, these 'hotspots' are very closely associated with increases in electricity generation, and would likely occur even with rate-based command and control regulation. The statistical analysis showed that while generation is by far the most important driver of NO_X emissions in the OTC NO_X Budget, the effect of the program is very significant as well.

More importantly, this research discovered no interview or statistical evidence for the 2000 ozone season that operators of large power plants respond to fuel or electricity prices by adjusting (in aggregate) plant operation to change NO_X emissions. This result is further supported by the comparison of a specific ozone episode with periods similar from an electric generation standpoint. Power plants appear to operate the same during high ozone periods as other periods of the year.

Policies, both proposed and adopted, for dealing with hotspots in emission trading systems have tended to introduce uncertainty and inflexibility into the markets. These have (or would have) reduced the efficiency of the market and thus limited the cost savings available, and in the case of RECLAIM they probably contributed to the failure of the program. While there is no doubt that emission trading systems may hypothetically increase the likelihood of hotspots, concern for this problem may be over-stated. A better policy may be to avoid provisions that limit trading or banking in the hopes of limiting temporal hotspots, but institute a regular system of review that would impose such limits if the potential for such a problem arose. These policies should be prospective, not retrospective, in order to minimize the uncertainty they introduce into the market.

Nonetheless, while this research has turned up no evidence that emission trading enhances any tendency towards greater temporal hotspots, it is undeniable that the flexibility built into such systems plus the mismatch between the phenomenon of concern and the regulatory period makes such a problem possible. Further, this study has some limitations. Most important is probably the fact that the OTC NO_X market is relatively small and illiquid, which limited participation and possibly limited the opportunity for firms to vary plant operation to optimize revenues associated with NO_X controls and allowance purchases. This would be accentuated by the fact that only the first three years of the program are evaluated and for the first, at least, there was very little familiarity with the program and no bank of allowances saved up. The relatively low prices for NO_X allowances (compared to the prices for power) may also be a factor – things may change as the cap decreases.

This paper suggests a number of areas for further research. One obvious issue would be to continue to look for temporal hotspot problems in C/T systems as the caps become tighter. A second would be to conduct a more detailed and disaggregated analysis of plant dispatch and utilization to verify the underlying causes of the residuals in the regressions above and the values that the coefficients take. Third, an analysis of the NO_X Budget program for spatial hotspots is clearly needed. Finally, air quality modeling may be needed to determine if any spatial and temporal differences in *emissions* caused by the OTC NO_X Budget have a significant effect on pollution concentrations or on health.

References

Atkinson, S. E. and T. Tietenberg (1987). "Economic Implications of Emissions Trading Rules for Local and Regional Pollutants." Canadian Journal of Economics **20**: 370.

Bernstein, M., A. Farrell and J. Winebrake (1994). "The Environment and Economics: The Impact of Restricting the SO2 Allowance Market." Energy Policy **22**(9): 748-754.

Blumsack, S., D. Perekhodstev and L. B. Lave (2002). "Market Power in Deregulated Wholesale Electricity Markets: Issues in Measurement and the Cost of Mitigation." Electricity Journal **15**(9): 11-24.

Burtraw, D. and E. Mansur (1999). "Environmental effects of SO2 trading and banking." Environmental Science & Technology **33**(20): 3489-3494.

Bush, G. W. (2002). Clear Skies Initiative. Washington, DC, The White House. Press Release.

Campbell, S. M. and A. S. Holmes (1993). "Going Once, Going Twice, Sold! EPA Auctions Pollution Rights." New York Law Journal: S10.

Carlson, C., D. Burtraw, M. Cropper and K. L. Palmer (2000). "Sulfur dioxide control by electric utilities: What are the gains from trade?" Journal of Political Economy **108**(6): 1292-1326.

Chinn, L. N. (1999). "Can the market be fair and efficient? An environmental justice critique of emissions trading." Ecology Law Quarterly **26**(1): 80-125.

Dorris, G., J. Agras, S. Burrows, M. McNain and S. Reynolds (1999). Development and Evaluation of a Targeted Emission Reduction Scenario for NOx Point Sources in the Eastern United States: An Application of the Regional Economic Model for Air Quality (REMAQ). Washington, DC, U.S. Environmental Protection Agency. November 24.

Drury, R. T. (1999). "Pollution Trading and Environmental Injustice: Los Angeles' Failed Experiment in Air Quality Policy." Duke Environmental Law and Policy Forum **9**: 231.

Dudek, D. J. and J. Goffman (1992). "Can Preapproval Jump-Start the Allowance Market ?" Electricity Journal: 12-17.

Farrell, A. (2000). "The NOx Budget: A Look at the First Year." Electricity Journal **March**: 83-92.

Farrell, A. E. (2001). The Political Economy of Interstate Public Policy: Power-Sector Restructuring and Transboundary Air Pollution. In Improving Regulation. S. Farrow and P. Fischbeck, Eds. Washington, DC: RFF Press. pp. 115-141.

Farrell, A. E. (2003). Clean Air Markets. In Encyclopedia of Energy. C. Clevelenad, Ed.: Academic Press. pp. forthcoming.

Farrell, A. E., R. Carter and R. Raufer (1999). "The NOx Budget: Costs, Emissions, and Implementation Issues." Resource & Energy Economics **21**(2): 103-124.

Farrell, A. E. and G. Morgan (2003). Multi-Lateral Emission Trading: Heterogeneity in domestic and international common pool resource management. In The Commons in the New Millenium: Challenges and Adaptation. E. Ostrom and N. Dolšak, Eds. Cambridge: MIT Press. pp. forthcoming.

Foster, V. and R. W. Hahn (1995). "Designing More Efficient Markets: Lessons From Los Angeles Smog Control." Journal of Law and Economics **38**(1): 19-48.

Fromm, O. and B. Hansjurgens (1996). "Emission trading in theory and practice: an analysis of RECLAIM in Southern California." Environment and Planning C: Government and Policy **14**: 367-384.

Israels, K., R. Grow, A. Campbell, A. Liddell, A. Schwarz and D. Pekelney (2002). An Evaluation of the South Coast Air Quality Management District's Regional Clean Air Incentives Market - Lessons in Environmental Markets and Innovation. San Francisco, U. S. Environmental Protection Agency Region 9. November. 69. http://www.epa.gov/Region9/air/reclaim/index.html

Johnson, S. L. and D. Pekelney (1996). "Economic assessment of the regional clean air incentives market: A new emissions trading program for Los Angeles." Land Economics **72**(3): 277-297.

Milford, J. B., D. F. Gao, A. Zafirakou and T. E. Pierce (1994). "Ozone Precursor Levels and Respones to Emissions Reductions - Analysis of Regional Oxidant Model Results." Atmospheric Environment **28**(12): 2093-2104.

Nash, J. R. and R. L. Revesz (2001). "Markets and geography: Designing marketable permit schemes to control local and regional pollutants." Ecology Law Quarterly **28**(3): 569-661.

Nobel, C. E., E. C. McDonald-Buller, Y. Kimura and D. T. Allen (2001). "Accounting for spatial variation of ozone productivity in NOx emission trading." Environmental Science & Technology **35**(22): 4397-4407.

Nobel, C. E., E. C. McDonald-Butler, Y. Kimura, K. E. Lumbley and D. T. Allen (2002). "Influence of population density and temporal variations in emissions on the air quality benefits of NOx emission trading." Environmental Science & Technology **36**(16): 3465-3473.

Possiel, N. C. and W. M. Cox (1993). "The Relative Effectiveness of NOx and VOC Strategies In Reducing Northeast U.S. Ozone Concentrations." Water, Air, and Soil Pollution **67**: 161-179.

Raufer, R. (1998). Pollution Markets in a Green Country Town: Urban Environmental Management in Transition. Westport, CT, Praeger Publishers.

Solomon, B. and K. Rose (1992). "Making a Market for SO2 Emissions Trading." The Electricity Journal **5**(July): 58-66.

Stavins, R. (1997). "What can we learn from the grand policy experiment? Lessons from SO2 allowance trading." Journal of Economic Perspectives **12**(3): 69-88.

Swift, B. (2001). "How Environmental Laws Work: An Analysis of the Utility Sector's Response to Regulation of Nitrogen Oxides and Sulfur Dioxide Under the Clean Air Act." Tulane Environmental Law Journal **14**(Summer): 309.

U.S. Environmental Protection Agency (1998). Finding of Significant Contribution and Rulemaking for Certain States in the Ozone Transport Assessment Group Region for Purposes of Reducing Regional Transport of Ozone; Rule. 63 *FR* 57356. October 27

Zhou, H., K. F. Cen and J. B. Mao (2001). "Combining neural network and genetic algorithms to optimize low NOx pulverized coal combustion." Fuel **80**(15): 2163-2169.