Economics of Pollution Trading for SO_2 and NO_x

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March 2005 • Discussion Paper 05-05

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Abstract

For years economists have urged policymakers to use market-based approaches such as cap-and-trade programs or emission taxes to control pollution. The SO_2 allowance market created by Title IV of the 1990 U.S. Clean Air Act Amendments represents the first real test of the wisdom of economists' advice. Subsequent urban and regional applications of NO_x emission allowance trading took shape in the 1990s in the United States, culminating in a second large experiment in emission trading in the eastern United States that began in 2003. This paper provides an overview of the economic rationale for emission trading and a description of the major U.S. programs for sulfur dioxide (SO_2) and nitrogen oxides (NO_x). We evaluate these programs along measures of performance including cost savings, environmental integrity, and incentives for technological innovation. We offer lessons for the design of future programs including, most importantly, those reducing carbon dioxide.

Key Words: sulfur dioxide, nitrogen oxides, emission trading, power plants, air pollution

JEL Classification Numbers: H23, Q25, Q28, D78

Contents

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1. Introduction

State and federal governments have made significant progress toward improving air quality. However, attainment of the national ambient air quality standards remains elusive, especially for fine particulate matter and ground level ozone, one of the main components of "smog," and for reversing the ecological effects of acidification.

Air emissions from electricity generators are a major contributor to these pollution problems, including sulfur dioxide (SO_2) —which contributes to acid rain and fine particle concentrations in the atmosphere—and nitrogen oxides (NO_x), which contribute to both of these pollution problems and to ground-level ozone. The electricity sector emits roughly 68 percent of national SO_2 and 22 percent of NO_x.[1] The effects of the emissions of SO_2 are particularly strong in the Northeast, which is upwind of the large number of coal-fired generators located in the Mid-Atlantic States and the Ohio Valley. NO_x emissions also affect the Northeast but have a relatively bigger effect in western states.

Emission trading is now the centerpiece of federal policy towards control of SO_2 and NO_x. The year 2004 marked the 10th year of the national cap-and-trade program for SO_2 emissions from electricity generators established under Title IV of the 1990 Clean Air Act Amendments (CAAA). That same year saw the full implementation of a summer seasonal trading in NO_x emission allowances in the eastern 19 state NO_x State Implementation Plan (SIP) Call region. NO_x trading has also been used in Los Angeles and the surrounding region to help combat ozone problems.

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[1] EPA Current Emissions Trend Data base at http://www.epa.gov/ttn/chief/trends/.

This paper analyzes the use of the cap-and-trade approach in regulating SO_2 and NO_x emissions from electricity generators in the United States and considers four questions:

- Has cap and trade worked well in reducing emissions, improving environmental quality and doing so at relatively low cost? What are the key features of a cap-and-trade program that worked and what features were less successful?
- To what extent have the pollution problems that SO_2 and NO_X emission trading programs were designed to address been solved?
- If these problems are not yet solved, is a cap-and-trade approach still the best strategy for achieving further reductions in SO_2 and NO_x?
- What are the lessons for using a cap and trade approach to control emissions of other pollutants such as mercury and carbon dioxide (CO_2)?

After some general background information on the economics of emission trading and a short review of the related economics literature, the remainder of the paper is divided into two halves. The first half focuses on SO_2 and the second half on NO_x. The penultimate section of the paper is a summary of new initiatives to expand the use of emission trading, both under new stricter caps for SO_2 and NO_x and for other pollutants. The final section concludes with a summary of lessons learned.

2. The Foundations of Emission Trading

The first discussion of the use of economic instruments in environmental policy was from the British economist Pigou, suggesting the use of emissions fees or taxes as a way to internalize into private decisions the environmental costs of pollution (Pigou 1920). Emission trading was identified as an alternative far later by North American economists. Crocker (1966) proposed the idea of the government setting a cap on aggregate emissions and letting the market determine the emission price and the degree of abatement at individual facilities, rather than having the government set the price through an emission fee. Dales (1968) popularized the idea.

One can illustrate the simple underpinnings of emission trading by considering a control policy in the context of two facilities where the benefit of abating emissions at each facility is identical and equal to $1,000 per ton.[2] The cost of abating a level of emissions, A_i, at facility *i* is represented by the function $C_i\ (A_i)$, where *i*=1,2. Imagine that the cost of achieving a particular quantity of abatement ($\overline{A}$) at facility 1 is different from the cost of achieving that quantity at facility 2, that is $C_1(\overline{A})\ \neq\ \mathrm{C}_2(\overline{A})$. Assume also that it gets harder and harder for each of the facilities to reduce emission, that is, the cost per ton of abatement rises at an increasing rate. This is represented as positive first and second derivatives of the cost functions: $C_i^{'}(A)>0,\ C_i^{''}(A)>0,$ for $i=1,2.$

Presuming the environmental planner wishes to maximize the social net benefit of abatement—that is, benefits minus costs of abatement—we can represent the planner's problem as:

$$\max_{A_1,A_2}\ 1000\left[A_1+A_2\right]-C_1(A_1)-C_2(A_2)\ .$$

The mathematical solution requires that $C_1^{'}(A_1)\ =C_2^{'}(A_2)=1,000$; that is, social net benefit is maximized when the marginal cost of abatement at each of the facilities equals the marginal benefit of abatement. The marginal abatement cost, $C_i\ (A_i)$, is that cost associated with reducing an additional increment of pollution, while the marginal benefit, in this example a constant $1,000, is the additional benefit of reducing that increment. In order to obtain the greatest aggregate social benefit, the above solution implies that the actual quantity of emission reductions at each facility may be different. It also implies that the marginal abatement cost of facility 1 must equal the marginal cost at facility 2. This is the cost-effectiveness element of the optimal solution. For the social net benefit of abatement to be maximized, it follows that the actual abatement achieved must be realized at the least cost to society. This realization occurs when the marginal abatement costs across all facilities are equated.

An emission trading policy can achieve this solution, assuming that the affected facility have an incentive to minimize the cost of abatement. Suppose the marginal abatement cost of facility 1 is higher than the marginal abatement cost of facility 2. There exists some price per ton that facility 1 would be willing to pay facility 2 to increase its abatement so that facility 1 can lower its abatement while keeping total abatement constant. Facility 1 is better off because price it pays is less than the cost of abatement. Facility 2 is also better off because the cost of the additional abatement it must achieve is less than the price it receives from facility 1. Emission

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[2] For more general discussions on the economics of pollution control see Tietenberg (1985), Baumol and Oates (1988), and Klaassen (1994).

allowances (alternatively called permits) are the currency that facilitates this trade while protecting the environmental integrity of the program. An emission allowance is a legal and transferable right to emit a certain quantity of emissions (ounce, pound, ton, etc.). While they represent a right to emit, sources have an obligation to hold emission allowances equivalent to their total emissions in a particular compliance period (year, month, etc.). Emission allowances expire after use. To reduce costs, operators of affected facilities can buy and sell emission allowances. This incentive to trade allowances exists between the two facilities until their marginal abatement costs are equal.

The key feature of emissions trading is that allowing regulated facilities to transfer emission allowances should lead to a distribution of emission reductions that equates the marginal cost of emission reductions among facilities and therefore minimizes the total costs of emission reductions. Identification of the efficient level of emissions requires potentially extensive and uncertain information about the benefits and costs under any approach to regulation. However, once policymakers identify an environmental target, emission trading promises a cost-effective way to achieve that target and requires little information of the regulator. If a market is established for emission allowances, and if the regulator can monitor emissions to ensure that the aggregate emission target is achieved, then the regulator does not need information about the cost functions of individual facilities.

Most environmental regulations in the United States apply a uniform policy to sources of the same pollutant in the same industry. Often these policies require all sources to achieve the same maximum emission rate or use a particular abatement technology. This has been described as the command-and-control method of regulation. Such a prescriptive regulatory approach aimed at achieving the cost-effective outcome allowance trading achieves would impose a significantly greater informational burden on the government, given the different scales, vintages, and unique production techniques used by the affected sources.

The first application of emission trading was developed by economists and policy analysts in EPA’s Regulatory Reform group in 1975–76 who sought a way to permit localities violating the air quality health standards to support economic development without further increasing emissions. To accomplish this they designed a system of emission offsets whereby new emitting sources could pay existing sources to reduce their emissions sufficiently to offset any increase in emissions. Under this program, the local government could find emission reductions among its existing sources and provide them or sell them to newly established businesses, thereby offsetting emissions increases with reductions elsewhere. This approach featured bilateral trades and no aggregate cap on emissions. The government had to approve every transaction and often mediated these transactions, so it was far from the current emission trading model for SO_2 and NO_x. Nevertheless, emission offsets provided a way for to localities experiencing economic growth to avoid being constrained by clean air requirements. Variations on this theme including the "bubble" policy, whereby one could imagine placing a bubble over the multiple emission stacks of a plant and permit emissions of a particular type to be traded, (more precisely, allocated) among these stacks. EPA remained concerned only about the aggregate emissions from the metaphorical bubble. Bubbles could also cover smokestacks from multiple, if co-located, facilities. In the 1977 CAAA, Congress recognized the offset policy in law and also made it possible to "bank" emission reductions for later use.

A fully developed allowance trading policy encompasses many facilities and firms, and consequently complicated environmental considerations become relevant. For instance, imagine that the benefit per ton of emission reductions varies for each facility. To illustrate, imagine the marginal benefit per ton of abatement at facility 1 is \$1,500, and the marginal benefit at facility 2 is \$1,000. To maximize the social net benefit one can solve the problem:

$$\max_{A_1,A_2}\ \left[1500A_1 - C_1(A_1)\right] + \left[1000A_2 - C_2(A_2)\right].$$

The mathematical solution requires that $1,500 = C_1^{'}(A_1)$ and $1,000 = C_2^{'}(A_2)$. In other words, net benefits are maximized when the amount of abatement and the marginal cost of abatement vary at the two facilities. A parallel interpretation with subscripts indicating time periods instead of facilities would indicate that emission reductions at different times of day or times of year could be more or less valuable. The optimal structure for an emissions trading program will be altered if pollutants are not uniformly mixing in space or if emissions reduction at certain points in time are more valuable than at others. Montgomery (1972) established that if pollutants are not uniformly mixing in the atmosphere but instead the location of emissions matters to their environmental impact a system of emission allowances could be replaced with a system of allowances governing ambient air quality at receptor locations and the markets, one for each receptor, would in theory achieve the efficient outcome. Under an ambient allowance system, facilities would obtain and trade allowances that account for the impact of their emissions at each location.[3]

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[3] Tietenberg (1985) provides theoretical background and recorded evidence on hot spot issues in early trading programs, both with regards to the spatial dimension (pp. 60–92), and the temporal dimension (pp. 149–167). See also Tietenberg (1995), Krumm and Wellsich (1995), and Swift (2000a). Klaassen and Amann (1994) summarize alternative means by which spatial constraints can be incorporated into a system of tradable permits.

However, an ambient allowance system could be administratively complex, and enforcement would impose a substantially greater informational burden on the regulator, including the evaluation of the environmental effects of emissions from different locations. Simplified alternatives to ambient allowance trading that have been suggested include geographic allowance trading zones and the use of trading ratios between emission sources that reflect environmental effects (Tietenberg 1985; Krupnick et al. 1983).[4]

Where do trading programs for SO_2 and NO_x fit when considering the realistic details of this nature? Both pollutants exhibit complex temporal characteristics. SO_2 and NO_x lead to changes in fine particulates that affect human health in the near term and also contribute to long-term acidification. NO_x emissions also contribute to the formation of ground-level ozone, which is primarily a seasonal daytime problem of an episodic nature. Further, the environmental consequences of both types of emissions have complicated geographic impacts that depend on their location. However, as will be described below, SO_2 and NO_x emission trading programs in the United States have for the most part ignored spatial and temporal details in their design to focus instead on achieving the greatest aggregate amount of emission reductions. A focus of this review is whether the simple design of a cap-and-trade program, with or without spatial or temporal constraints, is in fact a wise policy choice for regulating SO_2 and NO_x and whether it is an appropriate model for regulating other pollutants.

3. Regulatory History of SO_2

SO_2 and its derivative pollutants are ubiquitous threats to public health and the environment. Given its potentially direct effect on human health, gaseous SO_2 emissions are regulated as a criteria air pollutant.[5] Today, the largest threat of SO_2 to public health is its role as a precursor to secondary particulates, a constituent of particulate matter, which is another criteria air pollutant. SO_2 and particulate matter are associated with human morbidity and mortality.

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[4] At least two other seminal concerns have emerged regarding the efficiency of emission permits. One is how uncertainty affects the design of regulation and the choice between emission fees and emission permits (Weitzman 1974). Another is the way that permit trading interacts with preexisting taxes and other regulations in the economy (Goulder and Williams 2003).

[5] Criteria air pollutants are those for which there are maximum ambient concentrations that all localities are expected not to exceed.

To help alleviate the contribution of SO_2 emissions to local air quality problems in the 1970s, utility companies constructed 429 tall stacks, many over 500 feet, on coal-fired boilers (Regens and Rycroft 1988). As a consequence, the vast majority of urban areas in the 1980s attained the national ambient air quality standards for SO_2. However, the smokestack remedy to local problems contributed to the deterioration of air quality at a regional level. Released high in the atmosphere, SO_2 emissions from coal plants travel hundreds of miles and convert to sulfates that, as particulates, degrade air quality and damage human health and visibility.

Furthermore, the elevated emissions have led to deposition of sulfuric compounds in soils and waterways in regions distant from the source of emissions. More commonly known as acid rain, deposition of sulfur compounds contributes to acidification of forests and lakes. NO_x emissions behave similarly and also contribute to acid rain.[6] Although secondary particulates and acid rain are national problems, they are most severe in the eastern United States. Most of the nation's high-sulfur coal is from the Appalachians and burned primarily east of the Mississippi River. Weather patterns move emissions farther to the east.

The 1970 Clean Air Act implemented performance standards for *new sources,* as well as for those that undertook major modification, based on emissions per unit of heat input. Collectively, these standards are known as new source performance standards (NSPS).[7] Since 1977 new coal-fired power plants have faced an emissions rate–based standard that effectively required the installation of flue gas desulfurization systems commonly referred to as "scrubbers." Although the emission limitation is nominally a performance standard, operators of new facilities cannot switch to low-sulfur coal to achieve comparable emission reductions, and the only technology available to meet the standard for either low- or high-sulfur coal is scrubbing.

The NSPS are seen as a way to improve environmental performance over time as older plants eventually retire. However, the power plants that existed before 1978 seem to have an almost indefinite life (Ellerman 1998). Prior to the 1990 CAAA, federal clean air policy treated new and existing coal-fired facilities unevenly, and many argue the NSPS has given a cost

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[6] Of the two contributors to acid precipitation, SO_2 is considered the more significant because most affected regions still have the capacity to buffer excess nitrogen. In the future, NO_x emissions may rise in significance, depending on the region's soil characteristics. See discussion in U.S. EPA 1995a.

[7] The actual emission reduction standards imposed on new plants or plants that undergo major modifications will be at least as stringent as the NSPS and often more stringent. Emission reduction requirements are typically determined on a case-by-case basis.

advantage to existing sources that has lengthened their life (Nelson et al. 1993). The 1990 CAAA bridged this gap by regulating SO_2 emissions from all new and existing power plants in a uniform manner, although NSPS remain in effect for new plants.

4. Design of Title IV SO_2 Trading Program

Title IV of the 1990 Clean Air Act Amendments regulates emissions of SO_2 from electricity-generating facilities under an emission trading program in order to reduce damages from acidification. The industry is allocated a fixed number of allowances, and firms are required to surrender one allowance for each ton of SO_2 emitted by their plants. Firms may transfer allowances among facilities or to other firms or bank them for use in future years.

A less widely acknowledged innovation of Title IV is the annual cap on average aggregate emissions by electricity generators. Unlike prescriptive technology-based approaches to environmental regulation, under which emissions are allowed to increase with economic growth, a central feature of the cap-and-trade approach is that emissions are fixed and it is the allowance price that fluctuates. However, the SO_2 program allows an affected source to retain for future use allowances allocated to a facility in excess of its emissions. That is, sources are allowed to bank allowances, such that in any year aggregate industry emissions must be equal to or less than the number of allowances allocated for the year plus the surplus accrued from previous years.

The law assigns allowances to each affected power plant unit based on its heat input during a historical base period (1985–1987), multiplied by an emissions rate calculated such that aggregated emissions equal the target emissions cap. Industrial sources are excluded from the mandatory program, but they may voluntarily enroll after establishing a historical emissions profile.

Under Title IV, the annual SO_2 allowance allocations are ultimately to be capped at 8.95 million tons. Annual emissions will average this level by about 2010 when it is expected that the emission bank will be depleted. The cap is approximately 10 million tons less than the amount emitted by utility facilities in 1980. Reductions to achieve the 8.95 million ton cap took place in two phases. Phase I began in 1995 and affected the 110 dirtiest coal-fired electricity-generating facilities including about 374 generating units. Virtually all of the Phase I units are located east of the Mississippi River. Phase II started in 2000 and covered all other coal-fired electricity-generating facilities with a capacity greater than 25 megawatts, plus smaller ones using fuel with a relatively high sulfur content, totaling about 1,420 generating units. In addition, the allocation to Phase I sources was reduced by slightly over half at the onset of Phase II.

Originally the SO_2 trading program was designed with two regions, one in the east and one in the west, to ensure that emissions were adequately reduced where damages from acidification were the most severe—in the east. Ultimately, the two-region model was abandoned and replaced by an SO_2 market with a single national cap, largely because the single-market approach was expected to result in greater cost savings from allowance trading (Hausker 1992).

The ability to bank allowances without restriction proved valuable to the political success of the program. Once firms had built up a bank of unused allowances, they had a vested interest in maintaining the value of those banked credits and thus in furthering the program itself.

5. Measures of Effectiveness for SO_2 Trading

The effectiveness of the SO_2 trading program can be measured in a number of ways including emission reductions and effects on environmental quality, performance of the market, effects on the cost of compliance and the implications of the trading program for technological change.

5.1. Emission Reductions

Title IV has produced substantial declines in power plant SO_2 emissions over the past 10 years. During Phase I of the program, SO_2 emissions fell dramatically relative to previous levels and also fell (although somewhat less dramatically) relative to levels that likely would have been obtained in the absence of Title IV (Ellerman et al. 2000). Total emissions in 1995, the first year of the program, were 11.87 million tons—25% below 1990 levels and more than 35% below 1980 levels. Although emissions from the Phase I units remained relatively flat between 1995 and 1999, emissions at the unconstrained Phase II plants rose causing total emissions to climb up to 13.1 million tons in 1998 and 12.5 million tons in 1999.

Total emissions from affected units were well below annual allocations throughout the Phase I period. The opportunity for units to voluntarily participate in Phase I is thought to have introduced adverse-selection leading to an increase in emissions of one to two million tons (Montero 1999). However, the unused allowances yielded a bank totaling nearly 11.6 million allowances by the end of Phase I.

During the first year of Phase II in 2000, total SO_2 emissions declined to 11.2 million tons-almost 40% below 1980 levels. Units that came into the program in Phase II account for the majority of allowances allocated in Phase II and the majority of electricity generation. However, they contributed less emission reduction than the “large, dirty” units regulated under Phase I. Ellerman (2003) estimates that five-sixths of the reduction in SO_2 emissions from a projected baseline in 2001 occurred at Phase I units. He finds that as a group these units have reduced emissions by 57%, while Phase II units have reduced them by 14% to date.

In 2002, total emissions from the sources affected by the SO_2 program declined farther to 10.2 million tons. They fluctuated up to 10.6 million tons in 2003, in part due to high natural gas prices and a decline in the availability of nuclear units. In Phase II emissions have exceeded the annual allowance allocations by between 1 and 1.5 million tons each year as utilities draw down the bank built up in Phase I. Emissions are expected to continue to be above the annual cap through the remainder of this decade as they gradually decline to the 8.95 million ton annual target. Nonetheless, despite drawdown of the allowance bank over the decade, emissions are expected to be substantially below the levels predicted in the absence of Title IV (U.S. EPA 2001).

5.2. The Environment

Two environmental pathways are especially important in assessing the effects of SO_2 emissions changes. One is the change in airborne particulate matter formed by SO_2. The public health benefits from the emission reductions have been widely cited in pointing to the program’s success. The second is the reduction in acid deposition. Although public health and ecological measures are primarily affected by the level of the aggregate emission cap, another important question is how trading *per se* has affected these measures.

5.2.1. Environmental Response

Changes in emissions of SO_2 are thought to have had the greatest economic impact through improvements in human health. The ex post public health response has not yet been measured, but changes in particulate concentrations have been measured and simulation models suggest dramatic improvements in public health that outweigh costs by over an order of magnitude (U.S. EPA 2001).

The main ecological concern about SO_2 emissions is acidification.[8] Environmental improvements associated with the decline in emissions are evident but the problems of acidification remain. Several researchers have observed decreases in sulfur deposition and, to a lesser extent, decreases in sulfate concentrations in surface waters during the 1990s (Stoddard et al. 1998, Driscoll et al. 1995, Driscoll et al. 2001). Indeed, a steady drop in sulfur deposition has occurred since the 1970s, due to implementation of new source performance standards after the 1970 Clean Air Act (Stoddard et al. 1998, Driscoll et al. 1995). However, ecological recovery is a slow process.[9] In the Northeast—with attention focused on the Adirondacks in particular—the change in deposition has led to observable changes in sulfur in streams and, with some delay, is expected to result in changes in acid neutralizing capacity. The southeast region has older soil and the solution will take even longer. While the ecosystem health of the Adirondacks is now relatively stable, in large parts of the southeast aquatic ecosystems are expected to continue to decline absent further reductions in acid deposition (Stoddard et al. 2003; Sullivan et al. 2004).

5.2.2. Environmental Hotspots

Environmental hotspots are spikes in pollution at specific locations or in specific time periods. Conceptually, such outcomes are possible if as a result of trading a high portion of allowances is used at a small number of facilities. Further, it is possible that particulate levels in some locations resulting from long-range transport of SO_2 could increase. Mixed in with concern over hotspots is concern about "environmental justice" and that the hotspots will be in impoverished or minority communities.

The economic logic of emission trading suggests that it should not generally lead to hotspots. It is reasonable to expect that the largest, dirtiest facilities should be able to reduce emissions most easily (that is, they should have relatively low marginal abatement costs) and hence emissions trading might lead to a "cooling" effect whereby the greatest reductions are in the areas most adversely affected historically from power plant emissions. In addition, massive reductions in aggregate emissions accomplished under the Title IV regulations should enable an overall welfare benefit that far outweighs incidental hotspot activity. Further, trades of SO_2 at a

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[8] SO_2 emissions also affect visibility and damage materials.

[9] Replenishment of base cations, a key component in the recovery of acid neutralizing capacity and ultimately of ecological recovery, will occur principally through mineral weathering of the bedrock, which takes anywhere from decades to centuries. Particulate emissions from industrial sources have been reduced thereby reducing the atmospheric deposition of base cations to watersheds.

national level cannot legally lead to violations of local ambient air quality standards for SO_2 because emission sources must comply with local standards as well as with the national aggregate cap-and-trade program. Yet, it is possible that emissions could increase in a local area if the area remains in attainment of air quality standards.

It is important to recognize that the cost savings associated with a trading program may enable greater emission reductions in the aggregate, which may outweigh small changes due to trading. Hahn and Stavins (1991) note that early emission reduction credit programs that predate the SO_2 cap-and-trade program were typically a translation of an existing prescriptive program into a trading program with limited associated gains for environmental quality.[10] In contrast, the SO_2 trading program incorporated a dramatic reduction in aggregate emissions and thereby offered gains to the environment, a point that has been very important in building political support for it. Kete (1992) indicates that the “cap with trading” approach of Title IV closed the political gap between proposals from industry that called for an 8 million ton reduction and from environmentalists that called for a 12 million ton reduction, yielding a compromise that accomplished roughly a 10 million ton reduction.

Given an aggregate level of emissions to be achieved under one type of policy or another, several authors have asked whether trading creates hot spots. Solomon and Lee (2000) argue that unfettered trading in a single national market is a mistake because it fails to adequately protect sensitive areas in the Northeast, particularly in New York State. This contradicts early forecasts of the effects of SO_2 trading by the National Acid Precipitation Assessment Program (U.S. NAPAP 1991). That study considered a fixed level of aggregate emissions and illustrated potential changes in emissions and deposition that could result from trading compared with an emissions rate standard at 120 facilities with the highest emissions rates. They found that trading would lead to no change or a slight reduction in sulfur deposition in the East (pg. 447), and slightly higher to moderately lower levels of deposition among all states (pg. 256).

Burtraw and Mansur (1999) model the effects of allowance trading and banking under the SO_2 program in greater detail and also find that trading could be expected to lead to reductions in deposition in the East compared to a no-trading baseline with aggregate emissions held constant. They also find a reduction in the concentration of airborne particulate matter, although the

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[10] The offset programs did require ratios such that 1.3 tons at existing sources would be avoided for every new ton produced. Controversy surrounded the authenticity of the emission reductions.

changes were inconsequential compared to the improvements achieved by the reduction in overall emissions.

Other research has also supported the theoretical expectation that emission trading should lead to a cooling of hotspots. U.S. EPA (1998a) shows that sellers and ultimate buyers of SO_2 allowances in Phase I tended to be located within 200 miles of each other, thereby minimizing the potential for geographic impacts. Swift (2000b) presents evidence supporting the notion that the largest, dirtiest plants clean up the most. With plants arranged in quartiles, the largest plants reduced emissions 24% below allocation on average, and the smallest reduced by 6%. Swift also argues that hotspot issues are likely to be unimportant relative to costs savings because from 1994–1998 interregional trades constituted only 3% of the total value of all trades. Swift also points out that there have been areas, such as Midwest states like Ohio, where allowances have been purchased from nonattainment regions that would lead to a decline in emissions in these areas. Furthermore Swift argues that differences in regulatory methods such as trading versus command-and-control are related far less to localized pollution levels than to factors including plant location, size, and utilization, which would collectively determine over 90% of localized pollution levels.

Swift (2004) finds that during Phase I of the program the greatest reductions in emissions by far (in tonnage and percentage) were in the Midwest, and cooling was the general result in practice. Phase II of the program has also produced encouraging results, although emissions by some facilities in the East have exceeded annual allocations due to withdrawal of banked allowances. It is notable that for a few western power plants, many of which have cheap access to low-sulfur Powder River Basin coal, emissions actually ended up above their baseline level, although below allocation levels that were calculated on the basis of projected growth in electricity generation.

Not all analysts agree with these findings. Shadbegian, Gray, and Morgan (2004) examine the health costs and benefits associated with Title IV within the market-based system compared to a command-and-control alternative. As in other studies they find estimated public health benefits of reduced SO_2 emissions under Title IV greatly exceed the costs and benefits from Title IV to be concentrated in the northeastern, north central, and southeastern states. However, they find that that low-income populations received slightly lower benefits on average from Title IV, raising environmental justice concerns, although predominately black and Hispanic communities received a disproportionately large share of benefits relative to their costs. They also find many facilities where emission reductions produce a larger net benefit (e.g. health and environmental benefits minus compliance cost) than were buyers of allowances (thus emitting more than their initial allocation). A US GAO study (2002) also provides some a critical view by projecting that although total emissions will decrease by about 2 million tons by 2020, in some parts of the United States there could be an increase due to emission trading.

In summary the hotspot issue remains an important consideration in the design of an emission trading program. The evidence from the SO_2 program is ambiguous. The geographic effects of trading may or may not be beneficial; however, clearly the geographic effects are very small compared to the aggregate benefits resulting from the reduction in overall emissions and probably are outweighed by the additional emission reductions afforded by trading compared to a more prescriptive command-and-control approach.

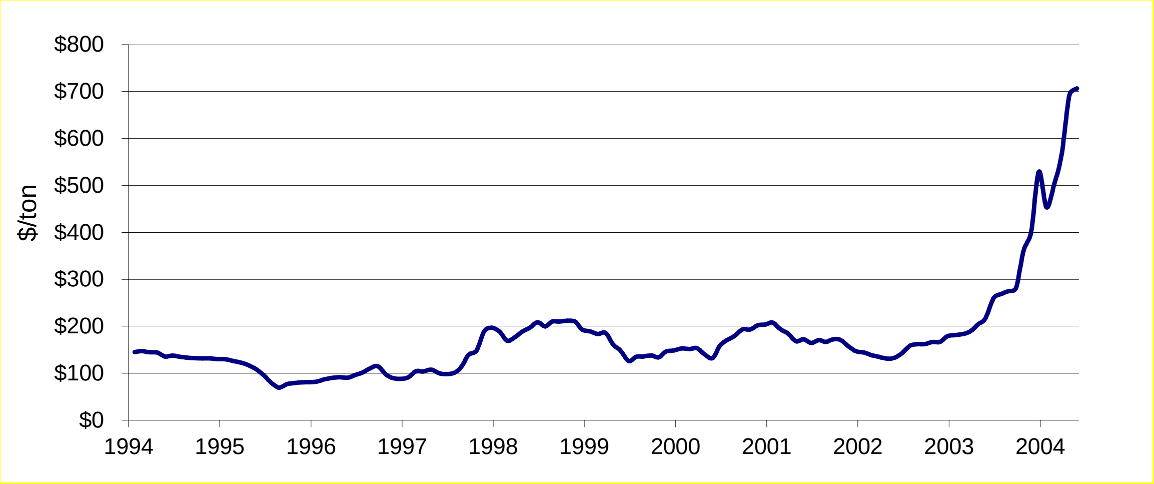
5.3. The SO_2 Allowance Market

The volume of SO_2 allowance trades has been significant. In the first three years of the SO_2 program the volume of trades between economically distinct parties roughly doubled each year compared to the previous year, suggesting a process of learning on the part of firms (Kruger and Dean 1997). The volume of interfirm trading peaked in 2000 at just under 15 million allowances and has declined each year since. In 2003, roughly 8 million SO_2 allowances were transferred between economically unrelated parties.

The path of allowance prices illustrated in Figure 1 tells a story about the evolution of the market. The price of an allowance started at close to $150 per ton and fell to about $70 by early 1996. Thereafter prices followed an upward path through 2003 at an efficient rate of increase that corresponded roughly to the opportunity cost of holding emission allowances in the bank (Ellerman 2003; Carlson et al 2000; Schennach 2000). During 1999, prices temporarily jumped to above $200 per ton, due in part to planning for Phase II and to changes in the status of the Clinton administration's efforts to tighten the particulate matter ambient health standard. Prices fell again in 2000 to close to $150 and remained relatively steady through 2003.

However, by the end of 2004 prices had risen to $700, due to an increase in demand for coal-fired generation in response to an increase in natural gas prices and in electricity demand. Also the Bush administration has made clear that restrictions on emissions of greenhouse gases would not be imposed in the near future. Meanwhile the administration proposal for new regulations would raise the value of banked allowances.

Figure 1. The history of SO_2 emission allowance prices.



5.4. Economic Performance

A variety of analyses have shown that trading has led to significant cost savings. In this section we review the estimates of cost savings and why estimates of cost savings have evolved. Subsequently we ask whether the market has led firms to achieve the least-cost solution. In other words, is the market efficient?

5.4.1. Cost Savings

One frequently cited measure of the SO_2 allowance market's success has been the observation that allowance prices are substantially lower than EPA and others predicted at the time the program was adopted. However, if used as a proxy for cost, the difference between forecasts and reality is exaggerated (Smith et al. 1998). One reason is that changes in fuel markets, including the decline in the delivered cost of low-sulfur coal and in the price of natural gas and oil in the 1990s contributed to a decline in emissions that would have occurred to some degree in the absence of Title IV. This led to a decline in the marginal cost of compliance, which set the price of allowances in the market.

A number of studies have directly measured the cost savings attributable to allowance trading by comparing total costs under trading with a hypothetical counterfactual policy that would have been adopted in the absence of the program. Intentionally missing is consideration of the influence of other potential regulatory actions, such as further control of particulates or NO_x emissions, or actions to address global warming. These studies consider an “enlightened” command and control approach (an emissions rate standard) as the alternative to trading. In reality, the alternative may have been less flexible and more expensive. For example, legislative approaches to controlling SO_2 seriously considered in the mid-1980s included forced scrubbing at larger facilities.

Most studies (Burtraw et al. 1998; White 1997; ICF 1995, 1990; White et al. 1995; GAO 1994; Van Horn Consulting et al. 1993) employ engineering-based estimates of compliance options and their costs. In contrast, Carlson et al. (2000) provide economic estimates that rely on a simulation model based on marginal abatement cost functions derived from an econometrically estimated long-run total cost function for electricity generation for a sample of more than 800 generating units from 1985 to 1994. From an economic perspective, this approach is superior to an engineering cost model because it takes into account substitution among inputs in response to changes in relative input prices. Moreover, it captures actual observed behavior of firms.

Carlson et al. estimate that the potential cost savings attributable to formal emissions trading, compared with the counterfactual of a uniform emissions rate standard, were $250 million (1995$) during Phase I of the program. They estimate the savings to be $784 million per year during Phase II, or about 43% of total compliance costs under a uniform standard regulating the rate of emissions at a facility. When compared with an alternative counterfactual policy that forces scrubbing to achieve the same level of emissions, cost savings of the program are estimated to be almost $1.6 billion per year.

Keohane (2002) uses econometric techniques to simulate decisions that would have been made under prescriptive SO_2 regulation and finds that the total number of scrubbers would have been one-third higher under a uniform emissions-rate standard chosen to achieve the same aggregate abatement as actually occurred under the cap-and-trade program. On the aggregate level, this translates into compliance costs of $150 to $270 million (1995$), or 16–25% per year higher than actually realized.

Ellerman et al. (2000) provide another estimate of cost savings that is based on an extensive survey of the industry, with extrapolation to estimate long-run compliance costs.[11] They estimate the cost savings from emission trading, inclusive of savings attributable to banking, to be about 55% of total compliance costs under a command-and-control approach. Hence, the two major studies of cost savings (Carlson et al. 2000 and Ellerman et al. 2000) are in general agreement on this estimate.

We mentioned previously that costs have declined over time with declining fuel prices (Ellerman and Montero 1998; Fieldston Company 1996; Burtraw 1996). Carlson et al. (2000) find that declining fuel prices lowered marginal control costs by about $200 per ton (1995$) over the decade preceding 1990. This trend continued into the 1990s. Hence, estimates of the cost of emission reductions and the cost savings from trading have both declined.

Another reason that cost estimates have fallen over time is that the trading program ignited a search for ways to reduce emissions at lower cost. A third reason is the role of exogenous technical change that clearly would have occurred in the absence of the program. Carlson et al. (2000) show that technical improvements, including in overall generating efficiency, lowered the typical unit's marginal abatement cost function by almost $50 per ton (1995$) of SO_2 over the decade preceding 1995.

The Carlson et al. model can help sort out the different factors' influencing estimates of marginal abatement costs. The authors assert that the flexibility implicit in the policy that allowed the use of low-sulfur coal was responsible for about 80% of the decline in marginal abatement costs while technical change was responsible for about 20%. For a benchmark scenario in which relative fuel prices and technology (including the utilization rate of scrubbers) remain stable at 1995 levels, the model predicts long-run marginal abatement costs will be $436 per ton (1995$). With prices held to their 1989 level (implying a higher price for low-sulfur coal relative to high-sulfur coal than obtained in 1995) and the time trend for technological change (factor productivity) also held at 1989 levels, marginal abatement costs rise to $560, a 28%

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[11] Ellerman (2003) provides another review of the SO_2 program and an explicit comparison of Ellerman et al. (2000) and Carlson et al. (2000).

increase. It is noteworthy that this is not far from the estimate ($579–$760 in 1995$) offered by ICF (1990) that formed the primary cost information for the U.S. EPA.[12]

5.4.2. Efficiency

There is ample empirical evidence of cost savings in Phase I, but this does not mean the allowance market was perfectly efficient. A measure of efficiency is convergence of the marginal costs of abatement to the price of allowances traded on the market. Joskow et al. (1998) and Schmalensee et al. (1998) find that the market for allowances was relatively efficient in the early years of the SO_2 emission trading program, noting that auction prices and private trading prices for SO_2 allowances were virtually identical by the end of 1994 and they point to growth in the level of trading volume from 1995 to 1997. Ellerman (2003) concludes that the level of banking that occurred was consistent with rational, cost-minimizing behavior on the part of utilities.

However, there is also evidence that the market did not lead firms to achieve their emissions reductions at *minimum* cost, i.e., to perform efficiently in the early years, and that some opportunities for cost savings were not realized. Carlson et al. find that, in the first two years of Phase I, marginal costs differed among facilities and actual compliance costs exceeded the least-cost solution by $280 million in 1995 and by $339 million in 1996 (1995$). Roughly speaking, this would erode about all of the potential gains from least-cost compliance. In contrast, Ellerman et al. (2000) provide an ex post cost estimate that is only about 3–15% above the modeled estimate of least-cost compliance in Phase I.

Several studies point to state public utility regulations and other state laws as influences that have tended to undermine the efficiency of the SO_2 market, leading many firms to pursue a policy of “autarchy” (no trade) and self-sufficiency in compliance in the first years of the program (Bohi 1994; Bohi and Burtraw 1997; Ellerman et al. 2000; Hart 2000; Swift 2001; Winebrake et al. 1995; Fullerton et al. 1997). Prior to implementation and during the early years of the program, many states felt a great deal of uncertainty about how regulators would treat allowance transactions in setting regulated rates, and this uncertainty damped utilities’ enthusiasm for using the allowance market (Burtraw 1996; Bohi 1994). Rose (1997) suggests that public utility commission (PUC) activities discouraged the use of the market in favor of strategies such as fuel switching. Rose et al. (1993) and Lile and Burtraw (1998) document a

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[12] The Carlson et al. (2000) preferred estimate of $291 assumes that utilization rates and performance of in-place scrubbers continue to improve and a slower retirement rate of coal-fired facilities.

number of PUC actions that promote use of locally mined high-sulfur coal coupled with scrubbing.

Arimura (2002) uses econometric techniques to examine the extent to which PUC regulations have affected the performance of the SO_2 market, focusing on compliance decisions at the generating-unit level. He specifically seeks to identify whether units with relatively low marginal abatement costs were reducing emissions while those with higher costs were buying allowances. Using data from Phase I and a probit model of the choice between fuel switching and allowance purchases, Arimura finds that, holding abatement costs and other characteristics fixed, generating units facing PUC regulations are more likely to rely on fuel switching for compliance rather than the allowance market.[13] He also finds that in states with high-sulfur coal, where efforts were made to protect local coal producers, allowance purchases more used more than fuel switching for compliance.

Sotkiewicz (2002) uses utility data for 1996 and exercised a simulation production cost model to evaluate facility performance. He also finds that PUC regulations governing cost recovery for investment in scrubbers led to cost increases ranging from 4.5% to 139% above least cost compliance.

Testing the efficiency of the SO_2 program has become a proving ground for the development of new techniques in production theory (Fare et al. 2004, 2003; Weber et al. 2002). This approach applies distance function methods to estimate how far the observed operation of (regulated) individual facilities is from efficient production. The indication from this literature is that significantly higher levels of efficiency were feasible early in the SO_2 emissions trading program than were actually realized, although cost savings were still considerable. Swinton (1998) finds that coal-burning electric plants with the highest emissions rates are also the plants with the lowest marginal abatement costs, a fact that may explain lower-than-expected prices in the new market for allowances. Coggins and Swinton (1996) study Wisconsin coal-burning utility plants to estimate the shadow price of SO_2 abatement, which they find to be above the allowance prices observed from the few trades that had occurred by then. Swinton (2002) provides stronger conclusions, through analysis of shadow prices of emissions reductions from

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[13] This finding contrasts with Bailey (1996) who was not able to verify that PUC decisions impeded use of the allowance market.

power plants serving Florida, and finds compelling evidence that plant owners had not taken full advantage of the opportunities for cost savings that the allowance market provided.

In an analysis of 40 plants from 1994-1998, Swinton (2004) finds no compelling evidence of the convergence of their marginal abatement costs among facilities, concluding that many power plants did not use the allowance market to its fullest potential. His results apparently contradict the expectation other authors voiced that the market is becoming more efficient over time. However, it is noteworthy that the years studied predate the implementation of competitive pricing of electricity in some parts of the country, which is thought to put increasing pressure on the entire industry to reduce costs.

In sum, the question about performance in the early years of the SO_2 trading program is one of perspective. Emission trading is a new institution that might be expected to pass through a period of transition before reaching a mature and efficient market. The issue is not only academic, because performance in the early years may be relevant to the design of trading programs in the future. Nonetheless, the literature appears to express almost uniformly the expectation of improved performance in the allowance market over time.

5.5. General Equilibrium Effects and Allowance Allocation

The discussion to this point has considered compliance costs only within the electricity sector. However, a full accounting of costs would take into account the interaction of the program with the full economy, including the preexisting tax system, such as the taxes on labor income. Recent theory asserts that any new regulation exacerbates the difference between the before-tax wage (or the value of the marginal product of labor to firms) and the after-tax wage (or the opportunity cost of labor from the worker's perspective), thereby raising the cost of regulation.[14]

Goulder et al. (1997) examine the SO_2 program using both analytical and numerical general equilibrium models and find that the tax interaction effect adds 70% to the estimated program compliance costs. This estimate assumes the entire electricity sector sets prices in the

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[14] A complementary issue is the effect on the measure of benefits. Williams (2002) demonstrates that the improvement in labor productivity from reducing pollution can have sizable positive effects when measured in a general equilibrium framework. Carbone and Smith (2004) find that nonseparability between environmental quality and other goods in the utility function and substitution between leisure and environmental quality, as may result if lost work results from air pollution changes in health status, will reduce the general equilibrium cost of the program.

market. If prices were instead based on cost of service then the regulatory burden would be much lower because allowances under Title IV were distributed at zero original cost. In fact only about half of the nation uses competitive pricing of electricity today. The authors find the tax interaction effect would be reduced substantially if the government auctioned the allowances and used the revenues from the auction to reduce preexisting distortionary taxes instead of giving allowances away for free.

Burtraw and Palmer (2004) draw on Goulder et al. (1997) and Carlson et al. (2000) to characterize the relative potential cost savings from allowance trading and the hidden costs of grandfathered emissions allowances compared with a command-and-control approach. Carlson et al. find that compliance (partial equilibrium) costs under the command-and-control scenario are 35% higher than the costs under a least-cost approach. Goulder et al. (1997) find that the general equilibrium costs of a policy in which emission allowances were auctioned are about 129% of the partial equilibrium measure of costs in the least-cost solution, and the costs of a policy that fails to raise revenues such as the SO_2 program represents about 171% of the least-cost partial equilibrium estimate. On net the general equilibrium measure of the cost of a command-and-control policy—a uniform emissions standard applied to all sources—is 178% of the cost of the least-cost solution in a partial equilibrium framework. In other words, the failure to raise revenue through the use of an auction with the use of that revenue to offset distorting taxes squanders much of the savings in compliance costs that could be achieved by a flexible tradable allowance system.

5.6. Compliance Choice and Technological Change

A large theoretical literature on the relationship between environmental regulation and innovation generally finds that the incentive for cost-reducing innovation is much larger with incentive-based regulation than with less flexible approaches such as facility-specific emission standards (Fischer, Parry, and Pizer 2003; Downing and White 1986; Milliman and Prince 1992, 1989; Zerbe 1970). The implementation of market-based policies for SO_2 emissions under Title IV has provided a somewhat unique opportunity to study the effects of emission allowance trading on technological change and innovation. This includes both effects on technology adoption and process changes at regulated firms and innovations in upstream input markets.

Several papers have been written that explore these issues, with approaches that include the simulation of compliance choices under different regulatory regimes and the econometric estimation of the implications of technological change and innovation on scrubber technology, fuel extraction and distribution, and on cost savings and efficiency. Researchers have also used patent data to conduct empirical studies of the relationship between regulation and technological change.

5.6.1. Compliance Choice

One of the key questions involved in technological change and Title IV regards the effects of the regulatory policy on the choice of abatement technique, with the use of scrubbers and switching among the types of coal used for electricity generation being the primary options. Some argue that Title IV's most significant impact was actually in the regulatory innovation of allowing abatement options other than scrubbing. Ellerman et al. (1997) estimate that 45.1% of emissions reductions in 1995 came from SO_2 scrubbing, with the remaining 54.9% coming from switching to other fuels, such as low-sulfur coal, and about half as many scrubbers as were originally anticipated were installed during Phase I. By 2001, during Phase II, Ellerman (2003) estimates that 37% of emission reductions were due to SO_2 scrubbers. All told thirty new scrubbers were installed on generating units. All of these were affected by Phase I, but three of the scrubbers were not brought on line until Phase II.

Other evidence bolsters the case that the flexibility associated with allowance trading has led to efficiency improvements that have reduced the cost of controlling SO_2 emissions. For instance Burtraw (2000) finds that blending of coals with different sulfur contents has enabled much greater reduction than had been anticipated before Title IV. Furthermore, the flexible nature of the SO_2 program enabled facilities to reduce the scrubber capacity needed to achieve roughly equivalent reductions in emissions. Prior to Title IV, scrubber systems usually included a spare module to maintain low emissions rates in the event that any other module became inoperative. One estimate indicates that a spare module would increase capital costs by one-third (U.S. EIA 1994). Allowances reduced the need for spare modules because allowances could be used for compliance during maintenance periods or unplanned outages.

Decisions about compliance depend importantly on the relative costs of fuel switching versus installing scrubbers. Technological change in these upstream markets plays an important role here, as addressed in the next two subsections.

5.6.2. Scrubber Costs and Performance

Another form of innovation the SO_2 allowance-trading program induced is improvement in scrubber performance. Burtraw (2000, 1996) argues that the flexibility associated with allowance trading created a form of competition with scrubbing, which provided incentives to reducing scrubbing costs. Keohane (2003) and Taylor (2001) both find that abatement costs per ton of removal have fallen substantially, especially in retrofitted scrubbers installed for compliance in the SO_2 program.

Part of the decline in scrubber costs was due to improved performance, which enabled an increase in the utilization of scrubbed units in Phase I (Ellerman et al. 2000; Carlson et al. 2000). Increased utilization is important to reducing the average cost of scrubbing because it spreads capital costs over a greater number of tons reduced. Before the SO_2 program, scrubbers did not exhibit reliability rates sufficient to achieve the current level of utilization. Popp (2003) finds that the move to cap-and-trade regulation for SO_2 in the late 1990s was accompanied by an improvement in the SO_2 removal efficiency of scrubbers. Keohane (2002) also finds that operating efficiency of scrubbers increased and brought about large declines in costs per ton of SO_2 removed. In contrast to other studies, Bellas (1998) produces less supportive empirical results, although without the benefit of a more recent dataset, finding that while operating costs seem to decline over the lifetime of a scrubber unit, no significant progress has occurred in abatement technology. Nonetheless, under Title IV recent vintages of scrubbers reduce potential stack emissions of SO_2 by 95 percent or more while the median emission reduction prior to the revised NSPS for SO_2 in the late 1970s was closer to 80% (Popp 2003, Taylor et al. 2003). The greater reliability of today’s systems also contributes to higher total SO_2 removal (Taylor et al. 2003).

5.6.3. Fuel Costs

The higher than anticipated reliance on low-sulfur coal was spurred in part by its low costs. Sales of low-sulfur coal (defined as less than 0.6 pounds of sulfur per million Btus) increased by 28% between 1990 and 1994 while prices fell by 9%. Meanwhile, sales of high-sulfur coal (defined as greater than 1.67 pounds of sulfur per million Btus) fell by 18%, although prices fell by only 6% (U.S. EIA 1995a, 1995b; Resource Data International 1995).

Two trends explain the accelerated decline in the price of low-sulfur coal. The most important has been the roughly 50% reduction in cost of rail transportation of low-sulfur western coal, driven by investment and innovation in the rail industry. To a great extent, this decline in costs would have occurred even in the absence of the SO_2 program due to the deregulation of the railroads under the Staggers Act (Ellerman and Montero 1998; Ellerman et al. 2000). A second explanation is that the higher capital and other costs expected for using low-sulfur coal failed to materialize because of the flexibility offered by Title IV and greater reliance on fuel blending (Burtraw 2000). Prior to Title IV, blending of different fuels was not thought to be feasible

(Torrens et al. 1992), but experimentation in response to the allowance market demonstrated that the detrimental effects of blending low-sulfur coal with other coals were smaller than originally thought.

The extent to which any portion of the decline in low-sulfur fuel costs is attributable to Title IV is subject to question. Studies by Kunce et al. (2004), and Keohane and Busse (2004) both find that the railroads, not the mines, captured rents from the large increase in post-1990 CAAA-driven demand for low-sulfur Powder River Basin coal, although Keohane and Busse (2004) propose a unique two-part tariff pricing scheme to explain these results. Kunce et al. (2004) conclude that the introduction of marketable emission allowances under the SO_2 program in 1990 had no effect on using low-sulfur coal to generate electrical power. Instead, declining costs both in mining and in rail transportation of coal appear to be responsible for this outcome. However, Burtraw (2000) provides anecdotes suggesting that the cost of low-sulfur coal delivered to eastern power plants fell because of dramatic investment and aggressive pricing aimed at capturing new markets that were available in part because of Title IV.

5.6.4. Patenting

Another line of research has taken advantage of more accessible U.S. patent databases to study the effects of regulation on patentable innovations in pollution abatement. Popp (2003), concludes that SO_2 regulation prior to 1990 created incentives for innovation directed primarily toward lowering the cost of operating scrubbers, while since the implementation of Title IV firms have had an incentive both to lower the cost of scrubbers and to improve their removal efficiency (and thus environmental effectiveness). While relevant yearly patent counts actually declined after 1990, the quality of innovations appears to have improved. This allows flexibility in emissions abatement choice, reducing the need for government to successfully “pick winners,” and research resources to be spread more efficiently. A subsequent international study of pollution control patenting by Popp (2004) finds that environmental regulation is associated with increased patenting in the United States, but not in other countries.

6. Regulatory History of NO_x

Emissions of NO_x contribute to fine particulates, acidification, and ozone. Although its contribution to particulate concentrations is usually identified as the more important impact of NO_x (U.S. EPA 1998b), the regulatory handles for reductions have stemmed from concerns about acid rain and attainment of air quality standards for ozone. Ozone is formed by the atmospheric mixing of NO_x and volatile organic compounds (VOCs) and facilitated by warm temperatures and sunlight. The electricity sector only contributes 22% of NO_x emissions in the United States, but it is the primary stationary source.[15] The vast majority of NO_x emissions comes from off- and on-road vehicles.

Stationary sources of NO_x emissions, particularly existing ones, faced little binding regulation until the 1990s. Like SO_2, since the 1970 amendments to the Clean Air Act new sources as well as those undertaking major modification have been subject to performance standards based on emissions per unit of heat input. Given the slow turnover of generation capital and, some might say, lax enforcement of these standards for modified sources, the new source provisions led to relatively minor reductions in NO_x emissions.

The 1990 Clean Air Act Amendments brought regulatory attention to existing NO_x sources in two ways. The first was through the acid rain provisions outlined in Title IV where a key component was the two million ton per year reduction of NO_x emissions from coal-fired boilers. Sources of NO_x faced additional attention in Title I of the amendments. Title I provided timetables and methodologies for the states to bring regions into compliance with national ambient air quality standards. The ozone standard was, and continues to be, a requirement that localities find particularly difficult to comply with, and their compliance efforts, sometimes aided by Congress, have involved various trading programs to bring NO_x emissions down (as well as many other types of programs).

Although the most widely recognized focus of Title IV are its SO_2 provisions, the contribution of NO_x emissions to acid rain was also addressed for the first time in Title IV. Title IV applied to existing coal-fired boilers emitting NO_x a traditional prescriptive approach similar to the type used for new sources. The requirements specify emission rate limitations, based on emissions per unit of heat content of the coal, expected to be achievable using particular abatement technologies. While these standards vary by the type of boiler, the presumed controls typically are combustion modifications such as low-NO_x burners. Because these are emission rate standards, it is possible for overall emissions to increase if fuel use rises. So, unlike a cap-and-trade program, if NO_x emissions from a source rise commensurate reductions are not required from other sources. Another interesting component of the Title IV NO_x provisions is that a company may average the NO_x emissions from its boilers as part of its compliance

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[15] EPA Current Emissions Trend Database at http://www.epa.gov/ttn/chief/trends.

strategy. That is, a boiler may emit above its assigned rate provided other boilers owned by the same firm are on net emitting below their allowable rates. The averaging provisions were often adopted.[16]

In regions in non-attainment with ozone standards, Title I required states to promulgate emissions rate limits for large point sources of both NO_x and VOCs. EPA suggested that the states adopt emission rates for affected coal-fired boilers that were essentially the same as those under Title IV. States generally followed this guidance and so boilers typically complied with the requirements of Titles I and IV simultaneously, with the important caveats that the Title I requirements came into effect sooner and allowed firms less flexibility.[17]

Most fossil-fuel burning facilities are not affected by the Title I emissions standard provisions, however, as they are not located in regions designated in nonattainment (typically urbanized areas). However, atmospheric modeling demonstrates that precursor emissions from sources outside the boundaries of nonattainment areas have an important influence on ozone formation in them. Indeed, many jurisdictions argue that pollution coming from sources outside their jurisdiction is sufficient for them to violate, or nearly violate the ozone standard, even if their own emissions were reduced to zero. While these external sources have an important influence on ozone concentrations in nonattainment regions, most states found it difficult to credit NO_x reductions from them towards their required Title I compliance activities. In part this is because they are actually outside the state and thus beyond the regulator's direct control, but it also was due to regulatory restrictions on what states could count towards compliance plan obligations in nonattainment regions.

An important exception to the limitations most states face in controlling NO_x emissions from upwind sources is found in the northeastern states. Congress recognized the need for a regional strategy for the Northeast corridor to achieve compliance with the ozone standard and created the Ozone Transport Commission (OTC) under Title I. The states that belong to the commission cooperated in the development of emission rate NO_x and VOC standards for point sources (as well as harmonizing compliance strategies for mobile sources). Recognizing that the emission rate standards would not be sufficient for ozone compliance, in 1994 the states agreed

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[16] Burtraw and Evans (2004) provide further discussion of the Title IV NO_X and inter-state NO_X policies.

[17] Some state regulations, like Pennsylvania's, also had averaging provisions similar to those provided under Title IV.

to implement a trading program for large sources of NO_x emissions. The OTC NO_x Budget Program began in 1999 and, focusing on the time when conditions for ozone formation are most favorable, regulates emissions from May 1 to September 30.

Meanwhile, other regions of the country faced continuing difficulty attaining the ozone standard in part because of their inability to control upwind NO_x emissions. Although most regions generally saw reductions in ozone concentrations since the 1990 amendments, from 1998 to 2000, 30 of the 98 regions that violated the ozone standard in 1991 continued to do so, while six additional areas had fallen into nonattainment. In response to concerns that they would not achieve the ozone standard, a collection of states including those in the Northeast and those stretching from the upper Midwest to the southeast, participated in a process known as the Ozone Transport Assessment Group. This, ultimately unsuccessful, process was an effort to develop consensus among the states for a coordinated effort to reduce ground-level ozone in the eastern United States. Many of the northeastern states also pursued reductions in NO_x emissions from upwind states employing Section 126 of Title I of the 1990 CAAA that allows states to petition the administrator of the EPA to require such reductions. In response to these concerns, the EPA proposed and subsequently promulgated a seasonal emissions trading plan for NO_x, known as the NO_x State Implementation Plan (SIP) Call Program, that began in 2003 and affects point sources in 19 eastern states. This program is modeled on the approach the northeastern states took but requires greater NO_x reductions and essentially superseded it.

One region that does not have problems with upwind pollution, but finds considerable difficulty in attaining the ozone standard nonetheless, is the Los Angeles basin. The basin is particularly susceptible to ozone formation due to surrounding mountains and warm temperatures that create an inversion layer in the air basin.[18] Fears about the inability to achieve the ambient ozone standard solely with prescriptive measures motivated the South Coast Air Quality Management District (SCAQMD) to start the first large urban cap and trade programs for NO_x in 1994.[19] This program is known as the REgional Clean Air Incentives Market (RECLAIM).

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[18] Of course, its large population and the heavy reliance on vehicle travel of its residents also contribute to the problem.

[19] The program also initially was intended to institute a cap with trading for VOCs and SO_2. The VOC program was not adopted due to concerns about measuring these emissions. The SO_2 program is smaller and less active than the NO_X program. Since this time additional urban NOx trading programs have been adopted in Texas.

The regional NO_x cap-and-trade programs have contributed to substantial reductions in NO_x emissions from point sources, but compliance with the ozone standard will continue to be a challenge. In part this is due to the difficulty in controlling mobile sources and in part to a 1997 tightening of the ozone standard. Expected to take effect sometime between 2009 and 2014, the new ozone standard averages air quality measurements over eight-hour time blocks rather than one-hour time blocks, increasing the difficulty of compliance. Had the new ozone standard been in effect from 1998 to 2000, 329 counties would have been in nonattainment.

7. NO_x Trading Programs

7.1 RECLAIM

The goal of RECLAIM was to reduce emissions from about 390 facilities by 8% per year from 1994 through 2003. A special feature of the trading market is that it has involved two zones, and trading between zones can only occur in one direction so that the implicit shift in emissions did not contribute to downwind pollution. One proposal would have involved 38 zones with a complex set of trading restrictions; however modeling indicated that environmental concerns could be satisfied with a two-zone approach that also was administratively simple enough to enable cost savings from trading (Johnson and Pekelney 1996).

A RECLAIM trading credit allows the holder to emit one pound of NO_x. The compliance period is annual with some sources reporting emissions from January to December and others from July to June. Sources in these two groups, or cycles, are provided allowances that may only be used in the compliance year they are allocated. So, allowances may not be banked, at least not in a straightforward manner. Because sources in the different cycles may trade with one another, the staggered allowance allocation provides some opportunity for intertemporal shifting of allowance use (emissions) if sources in separate cycles continuously swapped their allowances. There is some evidence for this behavior, but the extent is unclear.

A contentious issue in RECLAIM was the allocation of allowances. The program gave firms the flexibility to choose a baseline level between 1989 and 1992. This was a period of high economic activity, while in the first years of the program the economy was not thriving.[20]

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[20] U.S. EPA (2002) claims that the recession cannot fully explain why emissions were so far below total allocations in the early periods of the program. However, it does not identify a complementary explanation.

Coupled with the inability to bank allowances, there consequently was an ample surplus of emission allowances that expired unused, few real emission reductions, low allowance prices, and little trading of the early year vintages (Klier et al. 1997). Indeed, SCAQMD correctly anticipated that emissions would be far below allocations in early periods and this expectation contributed to the decision to prohibit banking (Coy et al. 2001).

In the first half of 2000 the performance of the market began to change as the price of a NO_x credit rose from $1 to $30 and meaningful trades began to take place. This tightening of the NO_x market was expected because the allocation in 2000 was close to the level of emissions in the immediately proceeding years (Coy et al. 2001). However, the cause of this run-up wasn't really the anticipated supply side phenomenon, but rather the abrupt increase in allowance demand from electricity producers due to the flawed deregulation plan in California.[21] By the spring of 2001 NO_x credits were trading at over $60 as demand for allowances substantially outpaced supply and sources began to fall into noncompliance, precipitating significant changes to RECLAIM that are described below.

7.2. OTC NO_X Budget Program

Created by the 1990 CAAA, the Ozone Transport Commission consists of 11 member states that include the northeastern and Mid-Atlantic States stretching from Maryland to Maine as well as the District of Columbia and northern counties of Virginia. The OTC NO_x Budget Program began with the signing of a memorandum of understanding in 1994 by all of the states in the region except Virginia.

The OTC NO_x Budget Program envisioned a three-phase effort to reduce emissions from large stationary sources, primarily electric utilities and large industrial boilers. The first phase of the program was simply the preexisting emissions rate standards required by Title I of the 1990 CAAA. The second phase of the plan marked the beginning of the cap-and-trade policy and was to run from 1999 to 2002. The third phase was to begin in 2003 and required a tightening of the emissions cap. By 2003, the emission cap would represent an approximate 70% reduction from the five-month summer emissions of 490,000 tons in 1990 from the affected sources. As

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[21] Additional evidence that this is the case comes from the RECLAIM SO_2 market. In 2000 the allocation of SO_2 allowances fell below historic annual emissions, but there was no dramatic price spike in this market. This is attributable to the absence of the electricity generators in the region, which fire natural gas and light oil, from the SO_2 market.

described above, the third phase of this program was scrapped once the federally managed NO_x SIP Call program was in place. An original proposal for the OTC NO_x Budget program envisioned three regions with constraints on trading among regions. In light of results of a market simulation model suggesting that such constraints were unnecessary, this approach was abandoned in favor of a unified market.

Unlike the RECLAIM program and the SO_2 trading program, the OTC NO_x Budget program requires a high level of coordination among states. The memorandum of understanding implementing the program laid out a procedure for calculating each state's emissions reduction responsibility from the affected sources and hence its share of the emissions cap. The NO_x cap was calculated by typically assuming a particular percentage reduction in emissions from each source where the assumed emission reduction depended primarily on the location of the source. Each state then had discretion as to how it allocated its share of the total cap, its "budget," to its affected sources. Each allowances allowed the holder to emit one ton of NO_x.

While the engagement of the states was clearly important to the development of the NO_x Budget program[22], the facilitating role of the EPA should not be underestimated. Drawing on its knowledge developing the SO_2 trading program, the EPA performed atmospheric modeling for the states and took the lead in developing, managing, and funding the program's emissions monitoring and allowance tracking systems (Donovan et al. 1997; Schary and Culligan 1997). The monitoring procedures generally relied on the pre-existing systems that affected sources had to adopt for compliance with the Title IV NO_x provisions. The EPA also participated in the development of a model rule that identified and suggested elements that should be consistent among the participating states' regulations.

A major conflict that regulators faced in the design of the OTC NO_x Budget Program was how to provide affected sources flexibility through banking while preventing a rapid depletion in banked allowances.[23] As a compromise, the trading program has a unique constraint on banking, called progressive flow control, which limits the number of allowances that can be withdrawn from a source's allowance bank rather than the number of allowances that can go into the bank. Once flow control is triggered, only a share of the allowances in *every source's* bank can be

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[22] See, for example, Farrell (2001).

[23] This concern ignores the incongruity between the annual time scale of the program and the daily scale of ozone formation.

withdrawn on a one-to-one basis. Once a withdrawal exceeds this share additional reductions are subject to a discount of two allowances per ton of emissions. The share that can be withdrawn on par with emissions is equal to the ratio of 10% of the total allocation to the total number of allowances banked *in the region*. The 10% value was chosen because it reflected the historical change in emissions that resulted in years when there was low nuclear availability in the region (Schary and Culligan 1997).[24]

Despite the generally agreed upon model rule, there were considerable differences in the state laws and regulations implementing the trading program, specifically in allowance allocation mechanisms and special programs that provided additional allowance allocations for the adoption of specific technologies. States typically did not attempt to affect the allowance market by restricting trades. Table 1, which follows, illustrates the variety of policies among the states.[25]

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[24] Unexpectedly, since the adoption of the program the performance of nuclear generators has increased dramatically (EPA 2003). The rise in nuclear availability is due to deregulation in the electricity market (Zhang, 2005).

[25] This table, while comprehensive, does not include all the information the authors have gathered on state programs. For more information contact David Evans at evans@rff.org.

Table 1 OTC NO_X Budget 1999-2002 Participation and Allocation Rules

State	Allocation Method[1]	Allocation Base	Early Reduction Credits	Set Asides	Trading Restrictions	Savings Restrictions	Allocations Continue if Shut Down
CT[2]	Annual Update and Use-or-Lose	*Industrial and Cogeneration Units, New Units* and *New Utility Units* receive enough allowances to satisfy their emissions subject to, at most, 95% of their allowable maximum emission rate. *Utility Units* receive at minimum a percentage of the difference between the reserves for the other unit categories and the state's NO_X Budget.	Yes, based on '97 and '98 over-compliance	No	No	Only for use-or-lose allocations	Yes
DE[3]	Fixed Allocations	1990 Emissions, OTC NO_X Budget (USEPA 1995b)	Yes, based on '97 and '98 over-compliance	No	No	No	Yes
MD[4]	Fixed Allocations and Use-or-Lose	Allocations are listed for existing sources. Recent sources ('90–'98) have a maximum use-or-lose allocation. Half the forfeited allowances are distributed to existing sources and half are retained by the state. Post-'98 sources receive no allocation.	Yes, based on '98 over-compliance	No	No	Only for use-or-lose allocations	Yes
MA[5]	Fixed Allocations, Use-or-Lose and Annual Update	*Full Allocation Units* receive enough allowances to satisfy their emissions subject to a predetermined maximum allocation (use-or-lose units with a '99 caveat). *New Units* provided allowances subject to availability in first operating season, and then become *Full Allocation Units*. *Special Units* receive a fixed	Yes, based on '97 and '98 over-compliance	New Source: 500 tons	No	Only for use-or-lose allocations	Only for Special Units and Utility Units

State	**Allocation Method[1]**	**Allocation Base**	**Early Reduction Credits**	**Set Asides**	**Trading Restrictions**	**Savings Restrictions**	**Allocations Continue if Shut Down**
		allocation of allowances each season. *Utility Units* receive at minimum a percentage of the allowances remaining after the new source set aside, the full allocation set aside, and the special unit allocations.					
NH[6]	Fixed Allocations and Use-or-Lose	Allocations for existing sources are listed in regulation without any indication as to how they were determined. New sources are allocated allowances equal to emissions, subject to availability.	Yes, based on ’98 over-compliance	Combined New Source, Energy Efficiency, Renewable Energy: 445 tons.	Minimal	Only for new sources	Yes
NJ[7]	Annual Update	Allocations are based on historic heat inputs (the highest two of previous three seasons) *and* historic emissions rates (the corresponding emission rates of the previous three seasons with the two highest heat rates) in combination with actual emissions.	Yes, based on ’97 and ’98 over-compliance	New Source, Growth Reserve, and Energy Efficiency	No	No	No
NY[8]	Fixed Allocations and Use-or-Lose	Allocations are listed in regulation without any indication as to how they were determined. New sources are allocated allowances equal to emissions, subject to availability.	Yes, based on ’97 and ’98 over-compliance	New Source: 250 tons For Energy Efficiency: 115 tons	No	Only for use-or-lose allocations	Yes
PA[9]	Fixed Allocations	Allocations are listed in regulation without any indication as to how they were determined.	Yes, based on ’97 and ’98 over-compliance	No	No	No	Yes
RI[10]	Fixed Allocations	Allocations are listed in regulation without any indication as to how they were determined.	No	No	Yes[11]	Yes	Yes

Notes for Table 1:

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[1] *Fixed allocation*: Allocation where sources know for four years of phase 2 a minimum allocation they will receive. Generally this what is referred to as grandfathering.

Use or lose: Sources allocated allowances based on their actual emissions in that year and no more (but perhaps less). Provides no incentive to reduce emissions in order to sell allowances.

Annual Update: Total allocation is updated annually. Formula for allocation in each year is based on behavior in immediately proceeding years (usually 1 to 3 years back). Works as a subsidy to whatever increases (production, input use, emissions) a source's allocation. For more, see Burtraw et al. 2002.

[2] Regulations of Connecticut State Agencies, Title 22a. Environmental Protection, Department of Environmental Protection, Abatement of Air Pollution, Sec. 22a-174-22a *The Nitrogen Oxides* NO_x *Budget Program*.

[3] Regulation No. 37 : NO_x Budget Program

[4] Code of Maryland Regulations (COMAR), Title 26 Department of the Environment, subtitle 11 Air Quality, Chapter 27 Post RACT Requirements for NO_x Sources (NO_x Budget Program) and Chapter 28 Policies and Procedures Relating to Maryland's NO_x Budget Program.

[5] Code of Massachusetts Regulations (CMR), 310 Department of Environmental Protection, 7.00 Air Pollution Control, Section 7.27 NO_x *Allowance Program*

[6] New Hampshire Code of Administrative Rules. Chapter Env-A 3200. NO_x *Budget Trading Program*

[7] New Jersey Administrative Code (NJAC), Title 7, Chapter 27, Subchapter 31. NO_x *Budget Program*.

[8] Title 6 of the Official Compilation of Codes, Rules and Regulations of the State of New York (NYCRR). Chapter III. Subchapter A, Part 227, Subpart 227-3. Pre-2003 Nitrogen Oxides Emissions Budget And Allowance Program. Pre-2003 Nitrogen Oxides Emissions Budget and Allowance Program.

[9] Title 25. Environmental Protection, Part I. Department of Environmental Protection, Subpart C. Protection of Natural Resources, Article III. Air Resources, Chapter 123. *Standards for Contaminants,* NO_x *Allowance Requirements*.

[10] Rhode Island Department of Environmental Management, Office of Air Resources, Air Pollution Control Regulation 38. Nitrogen Oxides Allowance Program.

[11] The Rhode Island regulations state; "No budget source may transfer allowances from its compliance account for 1999 and each year thereafter, through and including 2002." The remainder of 38.7 describes conditions and procedures for transfers. It appears that Rhode Island sources can only buy emissions and only from outside the state. In 1999 all Rhode Island sources over controlled and none engaged in a transaction (1999 NATS).

The final allocation for 1999 for the states that participated in the OTC NO_x Budget program reflects a 54% reduction from these states' five-month summer 1990 baseline of 417,444 tons. Total emissions amounted to 174,843 tons, and the remaining allowances were banked. The program became a model for the decentralized multijurisdictional emissions trading program that took shape in the subsequent NO_x SIP Call Program (Schary and Culligan 1997).

7.3. The NO_X SIP Call

The OTC region is only a portion of the eastern United States that is significantly affected by transboundary movements of NO_x. As described above, the Ozone Transport Assessment Group was established to provide recommendations regarding ways to address this problem over a larger region. However, the group's final report, released in June 1997, provided few actionable recommendations.

In late 1997, under Section 110 of the 1990 CAAA, EPA exercised its authority to require states to impose restrictions on electricity generators and industrial sources of NO_x emissions to help downwind states comply with the ozone standard. The rule is known as the NO_x SIP Call, because it called on states to revise their state implementation plans that outline their strategies for complying with federal ambient standards. The NO_x SIP Call assigns each state a summertime NO_x emission budget for large point sources. Although this covers a broad area and the effects of emissions depend on their location, Krupnick and McConnell (2000) found that uniform one-for-one allowance trading within the region approximated a cost-effective outcome. A state has the flexibility to either require its sources to directly comply with the state budget or, as the EPA preferred, to participate in a regional cap-and-trade program. Other similarities of NO_x SIP Call to the OTC NO_x Budget Program include the flexibility of the states to determine how their budgets should be allocated, the flow-control restrictions on banking, and the allowance providing the right to emit one ton of NO_x.

The NO_x SIP Call initially targeted 22 states and the District of Columbia. Nearly 90% of the boilers covered in the Title IV program are located in these states. After legal proceedings the start date for the program was postponed until May 31, 2004.[26] The region was also reduced to 19 states and the District of Columbia. After 2004, the compliance season will begin May 1 and

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[26] Although the first year will have a shortened trading season, seasonal budgets (and thus NO_x allowances) are unaffected, allowing an average emissions rate that is higher than in subsequent years.

all affected states in the region except North Carolina will fully participate in the trading program. Rather than initiate the third phase of the NO_x Budget Program, states in the OTC region choose to comply with the SIP Call restrictions starting May 1, 2003.

At the national level, the NO_x SIP Call is expected to lead to reductions of 22% from an annual baseline level of 5.4 million tons in 2007. National summer-season emissions are expected to fall by 40% from 2.4 million tons in 2007. In the SIP Call region, the program is expected to lead to annual reductions of 34% from projected baseline levels of 3.51 million tons in 2007 and summertime emission reductions of 62%, from 1.5 million tons to 0.56 million tons[27]

8. Measures of Effectiveness for NO_x Trading

As for SO_2, we consider whether the environment is affected by the spatial or temporal pattern of emission trading, the operational success of NO_x markets, and the ability of the programs to achieve cost savings.

8.1. The Environment

Until trading in the RECLAIM program was suspended in 2001, emission reduction targets were achieved and evidence suggests that there was no distinct shift in the geographic distribution of emissions (Luong et al. 2000). Similarly, for the OTC NO_x Budget Program, Swift (2004) finds very little emission shifting, as emission reductions in most states (especially large ones) were close to the average of 11%. Slightly greater emission reductions occurred in New England, while emissions were slightly higher in Maryland; fortunately the shift was north-south in nature and thus did not contribute to hotspots. Emission reductions in the western part of the region were equivalent to the reductions in the east. Moreover, Swift (2004) finds that the largest emitters prior to implementation of the program had disproportionately large reductions in emissions, suggesting that areas most greatly affected by NO_x emissions have realized the greatest benefits.

Moving from spatial to temporal shifting of emissions, Swift shows the program resulted in lowering NO_x emissions both in total and on high emissions days. Farrell (2003) uses more

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[27] U.S. EPA 1998b, Figure 2-4 and Table 2-4. One reason these numbers are approximate is that the reductions pertain to EPA's original program that targeted 22 states and the District of Columbia.

sophisticated techniques to show specifically that average and peak emissions have been lowered in equal proportion, alleviating concerns about temporal hotspots. Given that reductions occurred both in total and on high emissions days one may begin to draw the conclusion that cap-and-trade programs are perhaps more effective than rate-based standards in consistently reducing emissions regardless of short-term changes. However, it cannot be ignored that the rate-based standards are still effective during the ozone season and perhaps prevent particularly excessive emissions in a short-term period. Farrell (2003) suggests that this combination of regulations may be preferred to unrestricted allowance trading.

8.2. The Allowance Market

8.2.1 RECLAIM

The RECLAIM market has been marked by regulatory uncertainty since its inception (Klier et al. 1997). As mentioned above, the crisis of the California electricity market led to dramatic changes in the design of RECLAIM. The electricity market in California was deregulated in 1998 and, mostly due to the poor design of the deregulation program, sufficient generation capacity was not available.[28] As a consequence, in 2000 less frequently used generators in the Los Angeles area were pressed into extensive service. In 2000, electricity generators were allocated 2,350 tons of credits (14% of the total allocation), purchased about 2,250 tons of credits, but emitted 1,100 tons over their total holdings (Coy et al. 2001; Ellerman et al. 2003).[29]

In May 2001, the SCAQMD removed the electricity generators from the RECLAIM market. They were also required to install pollution control technologies. In addition, all sources emitting over 50 tons were required to submit binding compliance plans in 2002. These plans describe how the sources will comply with RECLAIM until 2006 and are binding.

Could the contagion of the electricity market to the RECLAIM market have been avoided? RECLAIM is the exception that proves the rule with respect to allowance banking. One way to help avoid the spike in prices would have been to allow allowance banking (in a simple form) all along. Had banking been allowed, sources with low-cost abatement options would have

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[28] For details on the crises of the electricity market in California, see Joskow and Kahn 2002 and Brennan 2001.

[29] It is difficult to attribute exactly the share of emissions and allowances held in a particular year to sources given the overlapping allocation cycles.

had an incentive to adopt them early and retain the allowances for future periods, even in the case where allocations were higher than the current demand for emissions, as occurred in the SO_2 program.[30] By allowing banking, sources have a greater incentive to think about their long-term position in the market. Unconstrained banking also equilibrates prices across vintages of credits. In this case, rather than seeing abrupt price changes from year to year, the price signal, the sign of the scarcity of the credits, is clearer to all participants.

What of the unused credits from the early years of the program? The appropriate solution to the concern that some of the allowances banked in early years would not represent real emissions reductions would have been to reduce the cap, not eliminate banking. That emissions were below allocations in the early periods, and the price of allowances from those years was essentially zero, implies that additional reductions were costless. At the same time clearly there were health costs of those additional emissions. An opposing argument to banking is that a substantial increase in emissions in the region as a result of drawing down the bank would go against the goals of the program. However, because the caps are annual and ozone formation is an episodic problem,[31] the cap-and-trade program, rather than banking itself, is inadequate to prevent an increase in emissions on a day with particularly stagnant, warm air.

Some might claim that had a command-and-control program been in place in the Los Angeles area the compliance difficulties of 2000 wouldn't have occurred. But there were command-and-control policies affecting the electricity generators in urban areas elsewhere in California that provide a telling story (Lloyd 2001). During the crisis, generators in other California cities violated annual restrictions on NO_x emissions, operating hours, and fuel use. Where allowed emissions are a function of the amount of electricity generated or fuel used, these emission increases did not attract attention because with greater utilization these sources could legally emit more (and without commensurate reductions elsewhere or at another time, as would

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[30] Such behavior would also resolve uncertainty regarding the effectiveness of the abatement technologies at a more favorable time. Resolving these uncertainties before reductions are needed, rather than relying on just-in-time reductions, provides greater planning flexibility and price certainty.

[31] Few regulations of any nature address the short time horizons presented by ozone. Most approaches address operations over a longer time scale and thus don't assure reductions in those weather events when control is most needed. A market-based, but difficult to implement, solution to the situation where it is recognized that emissions need to be controlled in the near future and for a brief period of time is called episodic emissions trading (Bharvirkar et al. 2003).

be true under emission trading). So it seems unlikely that a command-and-control policy would have responded any better to the challenges faced in Los Angeles in 2000.

Were the changes made to RECLAIM in 2001 wise? The changes were to pull the electricity generators out of the market and require future compliance plans. These changes run counter to EPA's recommendation in its 2002 review of RECLAIM: "Once programs are up and running, major regulatory changes may be disruptive. Therefore, any actions taken to change or stabilize the market should be incremental and market based, rather than programmatic."

The requirement for future compliance plans commits the affected sources to control techniques that later on may not be advantageous. The effect on the market of the compliance plans is telling. Prior to the submittal date for the compliance plans, trading was very active as sources procured allowances. Since that time the market has been thin with few sources making trades on future year vintages. Thin markets can contribute to inefficiency (as the competitive pressure on the allowance price is relaxed). Thin markets also are an indication that firms are relying on go-it-alone strategies rather than relying on the market, implying a greater overall compliance cost for the abatement achieved.

A different way to address the problem of emissions increases beyond allowance holdings is to charge a preannounced fee on these excess emissions. This cap on allowance prices is called a safety valve, which provides insurance against the possibility of unexpectedly high allowance prices (Pizer 2002). Quite recently, the SCAQMD adopted provisions that bring the electricity generators back into the RECLAIM market. In addition, the total annual allocation is expected to fall about 11.7% from 2004 levels in 2007 and an additional 10.8% in 2008 (Unger 2005). To address spikes in allowance prices the new changes include a provision similar to a safety valve. If allowances go above $7.50 per pound, the SCAQMD could decide to increase annual allocations (up to 2004 levels) in the following year. But, unlike the safety valve, the decision to do so is at the discretion of the SCAQMD adding uncertainty to the market. In addition, sources may petition the SCAQMD for an exemption from the additional allowance reductions based on their adoption of stringent abatement controls. However, any reductions not taken from the allocations to sources that receive the exemption must be made up by sources that do not receive the exemption. Therefore no source knows exactly what its allocation will be starting in 2007 (Unger 2005).

8.2.2 OTC NO_x Budget Program

While the NO_x Budget Program can generally be considered a success, it had an inauspicious beginning that is evident in the allowance price fluctuations in the first half of 1999. Sources in Maryland surprised the market by not participating in the first season. Once it was realized these sources would not participate, allowances prices fell because Maryland sources were expected to be net buyers of allowances (Farrell 2000).[32] There were other delays in the adoption of state rules and the timing of their adoption that led to market uncertainty. Fortunately this difference across states was only in timing not content, so caused only short-term problems.

An additional source of market volatility in the early part of the NO_x Budget Program arose from uncertainty about the effectiveness of the primary strategies for compliance, which were load shifting and small operational modifications. The market could anticipate the cost of retrofit technology, but the performance of the operational strategies chosen was relatively unknown. Eventually it was recognized that operational strategies exceeded performance expectations (Farrell 2000). With the resolution of these uncertainties it became apparent that there were significantly more allowances than emissions, and prices in the summer of 1999 dropped substantially. By the end of the 1999 season so many allowances were banked that flow control was triggered.

Over the course of the program market activity was clearly robust as there were many transactions between economically unrelated sources and across state lines, suggesting that trading provided an opportunity to realize cost savings. However, as it became clear that the NO_x SIP Call program would replace the NO_x Budget Program, the price of allowances fell. Under the NO_x SIP Call there was a limit of 50,000 tons on allowances that could be allocated based on early emission reductions. The share of these early reduction allowances that northeastern states could allocate was much lower. As a result, many allowances banked under the NO_x Budget Program were not converted fully into NO_x SIP Call allowances. However, the possibility that these allowances could be converted to NO_x SIP Call allowances at a discount, and that in some states only OTC allowances of later vintage could be converted to SIP Call allowances, may explain why the size of the bank actually increased in later years and prices remained well above zero.

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[32] Two utilities initiated a legal challenge the rules implementing the cap-and-trade program in Maryland, thus delaying the state's participation. By 2000, the problem was resolved and the utilities participated in the program.

8.2.3 The NO_x SIP Call

Like the OTC NO_x Budget Program, the NO_x SIP Call experienced a large rise and then decline in the allowance price during its first season. The price for 2003 and 2004 allowances were fairly even leading up to the 2003 trading season.[33] The 2003 allowance price then rose from around $5,000 to $8,000, while the 2004 allowance price remained steady. The primary reason for the 2003 price increase was not regulatory uncertainty, however. Rather, it was the dramatic increase in natural gas prices that occurred during that period. In the Northeast, units that can fire both oil and natural gas often switch to natural gas during the ozone season, as it emits NO_x at a lower rate (Zaborowsky 2004).

The price of 2003 and 2004 allowances dropped dramatically, to less than $2,000 a ton, during the 2003 compliance period in response to unseasonably cool weather and the expectation that many allowances would be banked. Zaborowsky (2004) suggests that many firms that were to join the program in 2004 had just been allocated that year's allowances and were looking to sell them to raise cash given financial difficulties or to finance recently installed emission control equipment.

The 2004 season was generally uneventful. Although allowance prices moved significantly over the year, monthly changes were not particularly dramatic. However, explaining market price fluctuations is increasingly difficult given influence of companion markets like those for fuel and SO_2 allowances and proposed federal rules and regulations. At the end of 2003, and through the 2004 season, 2004 and 2003 allowances traded at a discount over 2005 allowances under the influence of flow control. Flow control was not triggered after 2003 given the large allocation in 2004, but that same large allocation, combined with a shortened trading season, led to expectations that flow control would be triggered for 2005. Flow control reduces the value of banked allowances compared to the current vintage. These expectations were realized and the allowance bank is about 37% of the total 2005 allocation (Evolution Markets 2004).

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[33] The allowance price data described in this section is provided by Evolution Markets: www.evomarkets.com.

8.3. Economic Measure of Cost Savings

8.3.1 RECLAIM

A cap-and-trade approach is expected to be less costly than a prescriptive approach that achieves the same reduction in emissions. Johnson and Pekelney (1996) simulate a variety of competing proposals for the RECLAIM program and compare them to the most likely command-and-control alternative. The authors employ a model that represents the option and behavior of market participants that wish to minimize their cost of program compliance. It is linked to both a regional general equilibrium model used primarily to capture employment effects and an atmospheric model that captures the behavior of emissions in the region. The command-and-control alternative is based on the SCAQMD’s 1991 Air Quality Management Plan that describes specific performance and technology standards for industrial categories and processes that RECLAIM was designed to replace.

Johnson and Pekelney find that the characterization of RECLAIM in their model that was most like the actual proposal at the time of their analysis would yield abatement cost about 58% less than the cost of the command-and-control option over the first six years of the program, for a total savings of $347 million (1987$). It was also shown that the RECLAIM option would likely cause less disruption in the labor market than the command-and-control policy.

8.3.2 Ozone Transport Commission NO_x Budget Program

Farrell et al. (1999) use a dynamic deterministic programming model to predict compliance cost of about $1 billion (1996$) for the second phase (1999–2002) of the OTC NO_x Budget Program. This represents an estimated $900 million in savings over the assumed alternative command-and-control approach, which assumes boiler level caps equal to its allocation under the cap-and-trade approach. There are no ex post estimates of the total abatement cost of the program as it was implemented. However, we expect that the total compliance cost was likely lower than the Farrell et al. cap-and-trade estimate because their model does not capture the effect of changes in the dispatch of generating capacity or the possibility of reducing NO_x through small operation modifications.

The Farrell et al. model predicts a price of $1,331 per ton in 1999, which rises to $1,718 by 2002 (1996$). The program uncertainty described above kept allowance prices above this range until the fall of 1999. Allowance prices eventually fell below these estimates attributable to the unexpectedly large number of allowances banked in the first year of the program. As noted above, sources realized more low-cost abatement methods through operational modifications than were anticipated. In the later years of the OTC NO_x Budget Program, downward pressure on allowance prices was further exerted by the limitation on the number of banked allowances that could be converted into NO_x SIP Call allowances, an outcome that could not have reasonably been anticipated by Farrell et al.

8.3.3 The NO_x SIP Call

Burtraw et al. (2001a) estimate that annual cost of abatement controls to achieve the reductions required by the NO_x SIP Call program is expected to be $2.1 billion (1997$). Assuming that the controls installed for seasonal compliance will be employed annually, they find that, using 2008 as an example, the program will reduce annual emissions within the region from 3.45 million to 2.43 million tons. The authors also predict that the price of an emissions allowance will be $3,401 (1997$). This compares with a predicted allowance price from their model of $1,356 for a policy representing the second phase of the OTC NO_x Budget Program. They do not model an alternative command-and-control approach.

The SIP Call policy has the additional interest of its influence on electricity costs. Burtraw et al (2001a) suggest that the policy will not have a large impact on electricity prices. Their model forecasts an average price increase of about 1.1%, from $64.4 to $65.1 per MWh (1997$), in 2008 in the SIP Call region. These results are sensitive to their predictions regarding the extent of electricity market deregulation, and thus how electricity is priced, in the SIP Call region. They assume that slightly more than half of the region's generation is priced under a regulated, as opposed to a market-based, regime. The affect of the SIP Call on the price of electricity would presumably be greater if there is greater deregulation of the market than they assume.

As part of its responsibilities when proposing new regulations, EPA also employed an electricity sector model to estimate the costs of the NO_x SIP Call policy. EPA's preferred analysis of the expected cost of NO_x reductions finds that the average cost per ton reduced is $1,807 (U.S. EPA, 1998b).[34] This study does not provide an estimate of the allowance price. U.S. EPA (1998) predicts a change in electricity prices of about 1.6%, assuming market-based

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[34] The EPA model assumes that controls installed in response to emissions standards under Titles I and IV are the only existing controls in the OTR for its analysis; Burtraw et al. (2001) use the OTR trading policy and its lower average emissions rates as its starting point. As such, there are fewer low-cost options available to affected sources in the Burtraw et al. study than in the EPA analysis. For a description of additional differences between the two studies, see Burtraw and Evans, 2004.

pricing throughout the electricity sector, and about 1.2% assuming traditional regulated pricing. The study does not indicate whether these predicted changes apply just to the SIP Call region or to the entire nation, however.

The primary focus in this discussion is cost, but it is noteworthy that net benefits (benefits minus cost) and cost-effectiveness are affected importantly by the limitation of the program to summer. Burtraw et al. (2003) examine 18 scenarios reflecting major sources of uncertainty in calculating benefits and costs and find that an annual policy would yield net benefits that are at least as great as those achieved under a seasonal approach. Some states, including New York, New Hampshire, and North Carolina, have recognized the value of reducing NO_x emissions on an annual basis and have adopted their own cap-and-trade programs to address this pollutant (and others).[35]

All of the estimates provided in this section are limited to compliance costs. As discussed above, the economic literature prefers a broader definition of the cost of regulation that includes a consideration of the interaction of new regulations or taxes with the effect of preexisting ones. None of the studies described above take the effects of tax interaction into account in their estimates. Goulder et al. (1999), analyzing a hypothetical NO_x cap-and-trade policy, find that general equilibrium costs are higher than compliance cost estimates.

9. Conclusions and Lessons

We have reviewed a wide range of program features and measures of performance of SO_2 and NO_x emissions trading markets in the United States, spanning a large existing literature. From this review we distill several conclusions regarding SO_2 and NO_x emissions trading and we offer some conclusions that speak to future regulations of as yet unregulated emissions from electricity generators.

- Emission cap-and-trade programs have proven to be an effective way to protect the environment. In the one exception, problems of NO_x emission violations (emissions in excess of the cap) visited on the RECLAIM program during the California electricity market crisis were also experienced at facilities subject to other forms of regulation.

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[35] For more on state efforts to reduce NO_x and SO_2 see Palmer and Burtraw (2005) and U.S. EIA (2004).

- Important hotspot effects have not emerged in the SO_2 or NO_x programs. Aggregate emission reductions have been far more important than the geographic location of emissions. For the national SO_2 and the large regional NO_x programs a single uniform market has been a wise policy design that expanded the opportunity for cost savings without sacrificing environmental gains.
- The SO_2 and NO_x cap-and-trade programs have generated sizable cost savings over CAC approaches and there is evidence that they have also induced technological improvement.
- The allowance markets appear reasonably efficient. But not all of the potential cost savings available from trading have been realized.
- Seasonal NO_x trading programs have done a good job of reducing ozone peaks through reductions in baseline NO_x emissions, despite the fact that NO_x emissions caps are not targeted to focus specifically on ozone peaks. An annual cap-and-trade program for NO_x makes sense as a way of generating further reductions in emissions to address concerns about particulates and other pollution problems such as nitrogen deposition and acid rain.
- Allowance banking has been an essential component of the SO_2 program. Its absence is a costly feature of the NO_x programs, eroding the opportunity for cost savings from interannual trading and contributing directly to the suspension of trading in RECLAIM.
- The efficiency of allowance trading would be increased if emission allowances were distributed initially through a revenue-raising auction.
- The cap-and-trade program is a good model for further reductions in SO_2 and NO_x emissions like those recommended in EPA’s Clean Air Interstate Rule or in proposed federal multipollutant legislation. We would recommend that banking be a provision of future programs for SO_2 and NO_x emission reduction.

We suggest some important lessons for using the cap-and-trade approach to regulate other pollutants.

- All of our conclusions regarding the use of cap and trade for SO_2 and NO_x generally hold for CO_2.
- An important difference between CO_2 and the other pollutants is the issue of allowance allocation. The costs of CO_2 reductions may be much larger than

previous programs, and inefficiency created by a free distribution may be much more significant (Burtraw et al. 2001b).

- For a toxic pollutant (and one with nonuniform dispersion properties) such as mercury, which EPA is planning to regulate with a final rule scheduled to be issued in March 2005, hotspots may be more of a concern and some limits on trading may be warranted.

The cap-and-trade approach to environmental regulation is not one-size-fits-all. Indeed, the effect is just the opposite, because this approach gives individual facilities the opportunity to tailor compliance activities to minimize cost while achieving society's environmental goals. Moreover, the cap-and-trade approach is not suited to all types of environmental problems. However, in the case of air emissions from large sources, cap and trade may now be the default approach. One might even reasonably ask: Why *not* use cap and trade to achieve large reductions in aggregate emissions?

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