October 2009 ■ RFF DP 09-40

DISCUSSION PAPER

U.S. Emissions Trading Markets for SO_2 and NO_x

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Abstract

The U.S. Clean Air Act Amendments of 1990 initiated the first large experiment in the use of market-based regulation to control environmental problems with the introduction of an emissions trading program for sulfur dioxide emissions. Later that decade the second large trading program began for control of nitrogen oxide emissions. Although these programs are widely viewed as successful, their development and the emergence of associated environmental markets took various turns that provide lessons for the development of new markets, including markets for greenhouse gas emissions. This paper reviews the history of these programs and provides a glimpse of their future given the introduction of new regulations affecting multiple pollutants and given the expected implementation of climate policy.

Key Words: market-based regulation, Clean Air Act, electricity generation, air pollution, sulfur dioxide, nitrogen oxides

JEL Classification Numbers: H23, Q25, Q28, D78

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Introduction

Two landmark emissions trading programs in the United States regulate the most significant conventional air pollutants: sulfur dioxide (SO_2) and nitrogen oxides (NO_x). We discuss the regulatory history that led to these programs, their design, and their effectiveness. Generally, cap-and-trade has worked well in achieving its stated goals of achieving emissions targets, resulting in substantial environmental and public health benefits. However, the emissions targets have not been sufficient to remedy the environmental problems, and the programs have not been flexible enough to adapt by reducing emissions further, even though costs have been substantially less than anticipated originally.

Most recent proposals to achieve further emissions reductions continue to suggest the use of cap-and-trade. Legislative initiatives to tighten the caps have failed primarily because of debate about whether to include controls on emissions of carbon dioxide (CO_2). In response, the Bush administration promulgated the Clean Air Interstate Rule (CAIR) in 2005, intending to use cap-and-trade to achieve substantial further reductions for only SO_2 and NO_x (and an accompanying rule aimed at mercury). It also introduced an annual NO_x cap while preserving as a separate market the five-month seasonal NO_x program, but with the latter expanded to a larger region. CAIR aimed to limit emissions in 25 states for SO_2 and annual NO_x emissions, with the justification of controlling particulates, and a slightly different 25-state region for controlling summer-season NO_x emissions with the intent of controlling ozone. In total, 28 states are affected by CAIR. Implementation of the CAIR rule was tangled up in the courts but is again proceeding, even as the rule has been remanded to the Environmental Protection Agency (EPA) for revision.

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* Dallas Burtraw is a Senior Fellow and Sarah Jo Szambelan is a Research Assistant at Resources for the Future. The authors acknowledge financial support from Mistra's Climate Policy Research Program. We appreciate assistance from Nathan Richardson and Susie Chung, and express a debt of gratitude to David Evans, Art Fraas, Gary Hart, and Karen Palmer for helping to shape our understanding of these issues.

The SO_2 and NO_x markets have been liquid and active, and according to most observers have worked well in achieving the emissions caps at less cost than would have been achieved with traditional approaches to regulation. There is evidence that both process and patentable types of innovation are attributable to the programs. At the same time, there is evidence that some cost savings have been not been realized. Moreover, despite substantial emissions reductions, ultimate environmental goals have not been achieved.

Several lessons from the SO_2 and NO_x markets emerge for the regulation of other pollutants such as CO_2. Most importantly, emissions caps achieve their stated goals and markets emerge as viable ways to reduce the cost of compliance. Transparent data systems, public access to information, and strict and certain penalties for noncompliance have led to a virtually perfect compliance record. However, we also observe that emissions caps are also emissions floors, specifying not only the maximum but also the minimum amount of emissions that will occur in most circumstances. This rigidity represents a failing of programs to take advantage of the revolution in information available to regulators. Allowance prices represent information about the economywide marginal cost of emissions reductions that has never been available previously to regulators, but thus far programs have not found a way to readily adapt given this information.

Another important lesson concerns the method for the initial distribution of emissions allowances. The approach used in the SO_2 program was “grandfathering,” that is, free allocation to incumbent emissions sources. The NO_x program began to experiment with other forms of allocation, including updating allocations over time on the basis of electricity generation and the use of revenue-raising auctions. The auction approach has special relevance for regulation of CO_2 because the value of emissions allowances can be substantial compared to the resource costs of achieving emissions reductions.

Recently the SO_2 and NO_x markets have been volatile and prices have fallen precipitously. These programs have been undermined by substantial regulatory uncertainty stemming from wavering enforcement of CAIR and also expected regulations on CO_2 emissions, an important copollutant of SO_2 and NO_x. Looking forward, we expect these markets to rebound. The expected revisions to CAIR by the EPA should strengthen the markets in the near-term. In the long run, if CO_2 emissions constraints are sufficiently tight, the emissions cap for the conventional pollutants will not bind and the emissions price for SO_2 or NO_x could fall to zero, ultimately signaling the end of these path-breaking environmental markets.

The Pollutants

SO_2 is a colorless gas with a sharp odor produced from the burning of fossil fuels (coal and oil). High concentrations of SO_2 can have serious effects on health, but more important today is its role as a precursor to the formation of particulates, a ubiquitous threat to public health and the environment. Particulate matter affects more people and has a greater economic consequence than any other conventional air pollutant (U.S. EPA 1998). SO_2 and particulate matter are associated with acute and chronic respiratory disease, heart disease, and premature mortality. Given their potentially direct effect on human health, gaseous SO_2 and particulate matter are regulated as criteria air pollutants.[1]

Long-range transport of sulfuric compounds also leads to the deposition of sulfur in soils and waterways in regions distant from the source of emissions. Sulfur deposition, more commonly known as acid rain, contributes to acidification of forests and lakes.

NO_x also contributes to fine particulates and acidification, but is less important than SO_2 in this regard. In addition, NO_x contributes to ground-level ozone, which is formed by the atmospheric mixing of NO_x and volatile organic compounds (VOCs) and facilitated by warm temperatures and sunlight. Policy to limit NO_x emissions has been driven largely by concerns about attainment of air quality standards for ozone and to a lesser extent concerns about acid rain.

Regulatory History of SO_2

The first large application of emissions cap-and-trade was the SO_2 trading program initiated under Title IV of the 1990 Clean Air Act Amendments in the United States. The success of this program has provided inspiration for other environmental trading programs. The Title IV trading program followed 30 years of command-and-control regulation of SO_2 and added substantially to the growing trend to incorporate flexibility mechanisms into environmental regulation.

In the early 1970s, before any market mechanisms were in place, SO_2 concentrations in many locales exceeded the national ambient air quality standards set under the Clean Air Act.

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[1] Ambient air quality standards are set nationally for criteria air pollutants in the United States. Criteria air pollutants are those for which there are maximum ambient concentrations that all localities are expected not to exceed in order to protect human health, especially vulnerable populations such as asthmatics, children, and the elderly.

These standards set ambient concentration levels for six pollutants, including SO_2, at levels determined to protect human health with an adequate margin of safety. In that decade, to help alleviate the contribution of SO_2 emissions to local air quality problems, electric utility companies constructed 429 tall stacks, many over 500 feet, on coal-fired boilers (Regens and Rycroft 1988). As a consequence, SO_2 was released high into the air, helping the vast majority of urban areas in the 1980s to attain 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, damage human health and degrade air quality and visibility. Further, the ultimate deposition of sulfur and nitrogen contributed to the problem of acidification.

Performance standards for new sources as well as existing sources that undertook major modification were initiated under the 1970 Clean Air Act and were expected to improve air quality as more new, relatively low-emitting plants were built and as older, unregulated plants eventually retired. The 1977 Clean Air Act Amendments tightened the new source performance standards (NSPS) to impose emissions removal rates that effectively required the installation of flue gas desulfurization systems, commonly referred to as scrubbers, even if the fuel used was low-sulfur coal. However, as Ellerman and Montero (1998) note, the power plants that existed before 1978 seem to have an almost indefinite life. Many have argued that the NSPS gives a cost advantage to existing sources that has lengthened their economic life (Nelson et al. 1993). Consequently, NSPS failed to achieve expected emissions reductions.

Areas that are in nonattainment with national ambient air quality standards can face sanctions under the Clean Air Act that have potentially severe economic consequences. Not only are these sanctions politically unpopular, but the standards themselves might restrict economic growth if they deny the opportunity to locate new production facilities. To overcome this barrier, the EPA designed a system whereby new emitting sources could pay existing sources to reduce their emissions sufficiently to offset any increase in emissions. Related programs included the "bubble" policy, which allowed a facility to comply with a standard defined over multiple sources rather than having to comply with individual restrictions for each smokestack or source. The 1977 Clean Air Act Amendments recognized the offset policy in law. These changes provided flexibility compared to the status quo, but the markets were informal. Trades had to be preapproved by the environmental regulator. There was limited ability to bank, some unused emissions reduction credits were lost, and the transaction costs for each trade approached 50 percent of the value of the trade. This set the stage for a major reform that was to follow.

Design of Title IV SO_2 Trading Program

Title IV of the 1990 Clean Air Act Amendments established the emissions allowance trading program for electric generating units. An individual firm is required to surrender one allowance for each ton of SO_2 emitted by its plants. Firms may transfer allowances among facilities or to other firms or bank them for use in future years.

Although allowance trading is the acknowledged innovation of Title IV, at least as important is the annual cap on average aggregate emissions. 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 aggregate emissions are fixed and it is the allowance price that fluctuates. Annual emissions may vary because of the opportunity to bank emissions across years, but over time the aggregate emissions level is fixed.

The law distributes emissions allowances to each affected power plant unit on the basis of 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. Only plants in existence by this base period receive an allocation, and their owners continue to receive the allocation even if these plants are retired. Newer plants must purchase emissions allowances. Industrial sources are excluded from the mandatory program, but they may voluntarily join the program if they could profit by providing low-cost emissions reductions.

The program was introduced 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 which 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 commensurate with achieving the 8.95 million ton target.[2]

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[2] Trading occurs within a single market. 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—the East. Ultimately, the two-region model was abandoned because the single-market approach was expected to result in greater cost savings from allowance trading (Hausker 1992).

Measures of Effectiveness for SO_2 Trading

Three measures of the effectiveness of the SO_2 trading program are its effect on environmental quality, the performance of the market, and an economic assessment considering several factors including cost savings, innovation, and the economic efficiency of compliance behavior.

Emissions Reductions and Environmental Quality

Title IV has produced substantial declines in power plant SO_2 emissions stemming directly from the introduction of an emissions cap. Total emissions in 1995, the first year of the program, were 11.87 million tons—25 percent below 1990 levels and more than 35 percent below 1980 levels.[3]

Emissions from the units that were covered during Phase 1 were well below annual allocations of emissions allowances to those units. The unused allowances yielded a bank totaling 11.6 million allowances by the end of Phase I. The bank 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. Furthermore, banking provided an opportunity to harvest low-cost emissions reductions, and in some cases that effort may have brought changes in operations or other innovations into practice sooner than otherwise may have occurred.

During the first year of Phase II in 2000, total SO_2 emissions declined to 11.2 million tons—almost 40 percent below 1980 levels. The units that joined the program in Phase II contributed less emissions 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. As a group, Phase I units reduced emissions by 57 percent, while Phase II units reduced them by 14 percent after 2000.

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[3] Emissions declined after 1990 and before the program was implemented in 1995, continuing a trend that started in 1980. However, a more precipitous drop began in 1993 due in part to the decline in the cost of low-sulfur coal. Emissions from the Phase I units remained relatively flat between 1995 and 1999, but emissions at the unconstrained Phase II plants increased, causing total emissions to climb to 13.1 million tons in 1998 and 12.5 million tons in 1999. 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).

Emissions were able to exceed allocations beginning in 2000 due to emissions banking. Before the introduction of CAIR in 2005, the bank was expected to be drawn down over a decade, leading average annual emissions to equal annual allocations of 8.95 million tons by about 2010. This target is approximately 10 million tons less than the amount emitted by utility facilities in 1980.

While emissions goals have been achieved, the environmental problems have not been solved. As indicated in the reference to Title IV as "The Acid Rain Program," the main acknowledged problem in 1990 was acidification. Over the last two decades sulfur deposition has decreased and, to a lesser extent, so have sulfate concentrations in surface waters. Indeed, a steady drop in sulfur deposition has occurred since the 1970s, corresponding to implementation of NSPS after the 1970 Clean Air Act and indicating the direct connection between emissions and deposition (Driscoll et al. 2001; Mische John et al. 2008). However, ecological recovery is a slow process.[4] While the ecosystem health of the Adirondacks is now relatively stable, in large parts of the Southeast, where soils are older, aquatic ecosystems are expected to continue to decline without further reductions in acid deposition (Stoddard et al. 2003; Sullivan et al. 2004).

Given this assessment of the environmental status, Banzhaf et al. (2002) indicate that the economic benefits from reduced acidification roughly equal the costs of the program. However, shortly after passage of the 1990 legislation, health and environmental economists began to emphasize the value of benefits from a different pathway—the improved human health effects of emissions reductions stemming from changes in air quality. Epidemiologic and economic models indicate that dramatic improvements in public health outweigh the benefits from reduced acidification from an economic perspective, and outweigh the costs of the program by an order of magnitude (Burtraw et al. 1998; U.S. EPA 2001; Muller and Mendelsohn 2009). These measures of benefits and costs suggest the program has been tremendously cost-effective. However, there remains a large difference between the marginal benefits and marginal costs of emissions abatement, indicating that emissions levels under the program remain too high to reap substantial economic benefits. The emissions reductions targets set under CAIR were originally designed to realize such untapped economic and health benefits (Napolitano et al. 2009).

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[4] 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. Paradoxically, the reduction in particulate emissions from industrial sources reduces the atmospheric deposition of base cations to watersheds.

One concern about emissions trading was the prospect that environmental hot spots could result at specific locations or in specific time periods. Solomon and Lee (2000) point to possible ecological hot spots and argue that unfettered trading in a single national market is a mistake because it fails to adequately protect sensitive areas in the Northeast. This contradicts early forecasts of the effects of SO_2 trading by the National Acid Precipitation Assessment Program, which finds that trading per se (under the cap) would lead to no change or a slight reduction in sulfur deposition in the East (U.S. NAPAP 1991, 447) and slightly higher to moderately lower levels of deposition among all states (U.S. NAPAP 1991, 256). Burtraw and Mansur (1999) modeled the effects of allowance trading and banking under the SO_2 program and also find that trading could be expected to lead to reductions in deposition in the East compared to a no-trading baseline at which aggregate emissions were held constant. The economic logic of trading suggests that the largest, dirtiest facilities should be able to reduce emissions most easily (i.e., they should have relatively low marginal abatement costs), and hence emissions trading might lead to a cooling effect rather than the creation of hot spots. Swift (2000, 2004) presents empirical evidence from Phase I supporting the notion that the largest, dirtiest plants cleaned up the most. The greatest reductions in emissions by far (in tonnage and percentage) were in the Midwest, the area with the greatest power plant emissions historically.

Concern about “environmental justice” pertains not to broad regional effects but rather to localized effects on specific communities. Shadbegian et al. (2004) examine the health costs and benefits associated with Title IV within the market-based system compared to a command-and-control alternative and find that that low-income populations received slightly lower benefits on average from Title IV, echoing environmental justice concerns, although predominately black and Hispanic communities received a disproportionately large share of benefits relative to their costs. A U.S. General Accounting Office study (GAO 2002) also provides a cautious view by projecting that in some parts of the United States there could be an increase in airborne pollution due to emissions trading.

In sum, the emissions reductions and environmental improvements from SO_2 trading have been substantial, but not sufficient to allow ecological recovery from the effects of acidification. There is little evidence to support the concern that trading per se would lead to ecological or public health hot spots, and substantial evidence to the contrary. The benefits overall outweigh the costs of the program by an order of magnitude, but the difference in marginal benefits compared to marginal costs indicates that the emissions targets have not been sufficiently low to maximize economic benefits.

SO_2 Allowance Market

Indicators that can shed light on the evolution and robustness of the SO_2 market include the volume of trading between economically unrelated firms and the price of allowances as determined in the market.

The volume of SO_2 allowance trades doubled in each of the first three years of the program. This suggests a process of learning on the part of firms (Kruger and Dean 1997). In 2000 the volume of interfirm trading reached nearly 15 million allowances, exceeding the allowances surrendered for compliance purposes that year. By 2005 the market had evolved such that 70 percent of allowance trading between economically unrelated firms was conducted by large electric companies and financial firms, and the involvement of financial firms helped to increase market activity (U.S. EPA 2009a). However, in more recent years, trading has declined. In 2008, when the CAIR ruling was vacated by the U.S. Circuit Court of Appeals for the District of Columbia, less than one million allowances were traded.[5]

Figure 1 illustrates the evolution of the allowance market. Allowance prices represent the marginal cost of abatement, which in turn is influenced by the cost of fuels (natural gas and coal) and abatement technology. At the beginning of the program allowance prices were close to $150 per ton and fell to about $70 per ton by early 1996. Thereafter prices rose through 2003. 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 (SO_2 plays an important role in the formation of secondary particulates). Prices fell again in 2000 to nearly $150 and remained relatively steady through 2003. Aside from volatility at the onset of Phases I and II, much of the small price volatility seen in the SO_2 market until 2003 could be correlated with volatility seen in energy markets (U.S. EPA 2009a).

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 electricity demand. Moreover, the Bush administration had made clear that restrictions on emissions of greenhouse gases would not be imposed in the near future, boosting demand for coal. The year 2005 saw large increases in prices for SO_2 allowances and natural gas. In March 2005 the CAIR proposal was finalized with emissions reduction goals of 70 and 60 percent below 2003 levels for SO_2 and NO_x, respectively. In response, the Title IV SO_2 market began to reflect the marginal cost of

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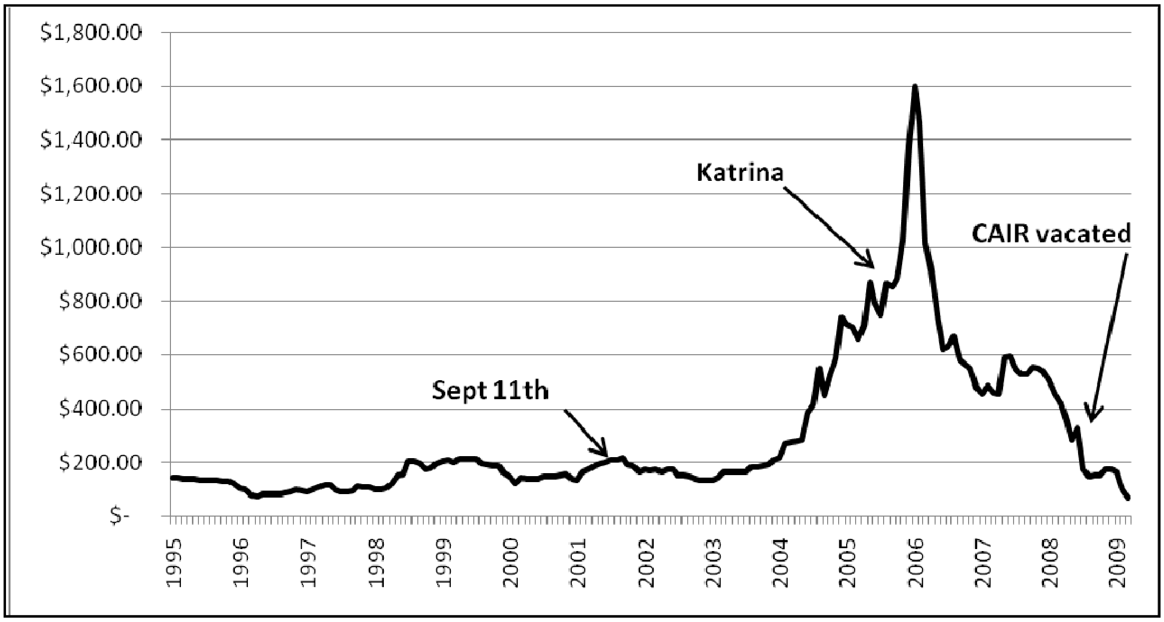
[5] Trading data were provided by Gary Hart of ICAP Energy.

future compliance with CAIR and the higher future value of banked allowances. In the same year natural gas prices rose dramatically in response to disruptions in supply caused by Hurricanes Katrina and Rita. Some analysts have speculated that the increase in natural gas prices also stemmed from anticipation caused by overly high SO_2 allowance forecasts (U.S. EPA 2009a). These combined pressures are demonstrated in a marked climb in monthly SO_2 allowances prices, which culminated at $1,600 per ton of SO_2 in December 2005 (Figure 1). In the following year, 2006, prices dropped as natural gas prices normalized, and evidence grew that there would be both an adequate supply of allowances and installed scrubber capacity to accommodate future CAIR compliance.

The remaining disruptions in the market are due to two rulings by the U.S. Circuit Court of Appeals for the District of Columbia. On July 11, 2008, the Court vacated CAIR, leaving it no clear plan for regulation beyond the provisions of the 1990 Amendments until later in that year, when the court remanded the ruling to the EPA. After a ruling is remanded, it remains in place until the agency can correct its flaws as identified by the courts. Combined with historically low natural gas prices, this regulatory uncertainty depressed allowances prices to $65 in March 2009. In the EPA auction, future vintage allowances sold for $6.65. We provide further discussion about the future of the SO_2 allowance market in the concluding section.

Figure 1. Monthly SO_2 Emissions Allowance Prices



Source: Data provided by Gary Hart of ICAP Energy.

Economic Assessment

Our economic assessment addresses the cost savings from cap-and-trade compared to conventional regulatory approaches. We also consider compliance choices and the relative benefits and costs of the program, the role of innovation, and finally the efficiency of compliance behavior.

Cost Savings

One frequently cited measure of the success of the SO_2 program is the observation that allowance prices are substantially lower, by a factor of four, than EPA and others predicted at the time the program was adopted. This good news may exaggerate the total cost savings under the program (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 even in the absence of Title IV (Ellerman et al. 2000). 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, taking into account changes in fuel markets. These studies consider an emissions rate standard as the alternative to trading, when in reality the alternative may have been less flexible and more expensive. Therefore the comparisons present conservative estimates of the savings. Most studies (Burtraw et al. 1998; White 1997; ICF 1990, 1995; White et al. 1995; GAO 1994; Van Horn Consulting et al. 1993) employ engineering-based estimates of compliance options and their costs. However, the two most convincing studies used empirical methods. Carlson et al. (2000) used econometric estimates, while Ellerman et al. (2000) used survey methods. These two studies are largely in agreement, finding savings of 43–55 percent compared to a uniform standard that would have regulated the rate of emissions at a facility. However, if compared to a mandate to use postcombustion controls, as earlier legislative proposals would have imposed, Carlson et al. (2000) estimate the savings are twice this amount.[6]

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[6] Another econometric study by Keohane (2002) simulates 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 percent per year higher than actually realized.

A great deal of attention has been given to the fact that costs have declined over time, largely due to 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. Exogenous technical change also would have occurred in the absence of the program. Carlson et al. (2000) show that technical improvements, including 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.

Innovation

Although fuel prices and exogenous technical change contributed advantageously to the decline in the costs of emissions reductions, cost estimates have also fallen over time because the trading program ignited a search for ways to reduce emissions at lower cost. It is clear that trading deserves substantial credit because every other approach used previously under the Clean Air Act, and nearly every other approach used in the 1990 Amendments, would have likely precluded affected sources from fully capitalizing on this advantageous trend in fuel prices and other factor markets. Furthermore, the flexibility under the trading program provided an impetus for investments in related markets, such as railroads and scrubber installations, that could not have been expected to the degree to which it occurred with a less flexible regulatory program in place.

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

One of Title IV's most significant impacts was in the regulatory innovation of allowing abatement options other than scrubbing. The flexibility offered by Title IV provided the opportunity for a greater reliance on fuel blending, which provided a transition compliance option to other compliance options (Burtraw 2000). Before Title IV, substantial 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.

Even more importantly, the higher than anticipated reliance on low-sulfur coal was spurred in part by its declining costs. The cost of rail transportation of low-sulfur western coal fell by roughly 50 percent, driven by investment and innovation in the rail industry. The extent to which any portion of the decline in low-sulfur fuel costs is attributable to Title IV is subject to debate. Kunce et al. (2004) conclude that the introduction of marketable SO_2 emissions allowances 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.

The Carlson et al. (2000) model can help to sort out the effect of different factors on the estimates of marginal abatement costs in the context of fuel switching. The authors assert that the flexibility to use low-sulfur coal was responsible for about 80 percent of the decline in marginal abatement costs, while technical change was responsible for about 20 percent. 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 supplies 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 percent 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 EPA.[7]

Declining fuel costs interacted with the cost of other technologies, including scrubbing, to achieve emissions reductions. Ellerman et al. (1997) estimate that about half as many scrubbers as were originally anticipated were installed during Phase I. In 1995 about 45 percent of emissions reductions came from SO_2 scrubbing, with the remaining 55 percent coming from switching to other fuels, such as low-sulfur coal. By 2001, during Phase II, Ellerman (2003)

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[7] The Carlson et al. (2000) preferred estimate of $291 assumes a continued improvement in utilization rates and performance of in-place scrubbers and a slower retirement rate of coal-fired facilities.

estimates that the portion of emissions reductions attributable to expanded use of scrubbing fell to 37 percent.

Even with a smaller role than anticipated for scrubbing, Burtraw (1996, 2000) argues the cost reductions in scrubbing emerged due to the competition between this and other compliance options. Keohane (2003) and Taylor (2001) both find that abatement costs per ton of removal fell substantially, especially in retrofitted scrubbers installed for compliance in the SO_2 program. Patent research helps explain the nature of the innovation. SO_2 regulation before 1990 created incentives for innovation directed primarily toward lowering the cost of operating scrubbers, while after 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) (Popp 2003). Under Title IV, recent vintages of scrubbers reduce potential stack emissions of SO_2 by 95 percent or more, while the median emissions reduction before the revised NSPS for SO_2 in the late 1970s was closer to 80 percent (Popp 2003; Taylor et al. 2003). 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.

Another aspect of improved performance was increased utilization, which reduces the average cost of scrubbing because it spreads capital costs over a greater number of tons reduced (Ellerman et al. 2000; Carlson et al. 2000). Before the SO_2 program, scrubbers did not exhibit reliability rates sufficient to achieve the current level of utilization. Popp (2003), Keohane (2002), and Taylor et al. (2003) find 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, because under the allowance trading system, an allowance saved is effectively a dollar earned.

Finally, one other reason the average costs of scrubbing fell was that before Title IV, scrubber systems installed under NSPS 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). Trading reduced the need for spare modules in retrofit scrubbers because allowances could be used for compliance during maintenance periods or unplanned outages.

Efficiency of Compliance Behavior

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 emissions trading program, noting that auction prices and private trading prices for SO_2 allowances were virtually identical by the end of 1994, and the auction continued to anticipate changes in the secondary market. Several authors suggest the general increase in prices corresponded roughly to the opportunity cost of holding emissions allowances in the bank (Ellerman 2003; Carlson et al. 2000; Schennach 2000). However, the ample evidence of market liquidity and cost savings does not directly address the question of whether the program has maximized potential cost savings.

This question is partially answered by other evidence suggesting that the market did not achieve maximum cost savings and that some opportunities for cost savings were not realized. Carlson et al. (2000) 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 3–15 percent above the modeled estimate of least-cost compliance in Phase I. In response to the suggestion that the increase in allowance prices corresponded to the opportunity cost of holding emissions allowances in the bank (Ellerman 2003; Carlson et al. 2000; Schennach 2000), Helfand et al. (2006) find that after adjusting for exogenous price shocks, SO_2 allowance prices do not increase at the rate of interest from 1994 to 2003, indicating an inefficient market. The authors suggest that the market may have been providing arbitrage profits to rent-seeking firms; firms may have lacked market experience and held allowances for fear of later scarcity; and transaction costs were larger than savings associated with trading.

Several early studies point to the role played by state public utility regulations and other state laws as influences that have tended to erode some of the cost savings that might have been achieved when viewed from a national perspective (Bohi 1994; Winebrake et al. 1995; Bohi and Burtraw 1997; Fullerton et al. 1997; Ellerman et al. 2000; Hart 2000; Swift 2001). Rose (1997) suggests that public utility commission (PUC) activities discouraged the use of the market in favor of strategies such as fuel switching. Arimura (2002) uses econometric techniques to examine the extent to which PUC regulations have affected the performance of the SO_2 market and finds that generating units facing PUC regulations are more likely to rely on fuel switching for compliance rather than the allowance market. He also finds that in states with high-sulfur coal, where efforts were made to protect local coal producers, allowance purchases were used more than fuel switching for compliance. Using utility data for 1996, Sotkiewicz (2002) obtains a similar result by exercising 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 percent above least-cost compliance. Distance function methods in production theory have also been used to test the efficiency of firm behavior under the SO_2 trading program. Coggins and Swinton (1996) study Wisconsin coal-burning utility plants and Swinton (2002) studies plants serving Florida. Both studies find that plant owners had not taken full advantage of the opportunities for cost savings that the allowance market provided.

Finally, as noted previously, the program has had an important failing if viewed from a broad perspective of benefit–cost analysis. Burtraw, et al. (2009) consider that if one assumes that a process of balancing led Congress to adopt a level of stringency with anticipated costs equal to forecasts in 1990, the ultimate decline in costs should have led Congress to purchase additional emissions reductions. If a price floor one-third below anticipated allowance prices had been in place, it would have triggered additional emissions reductions that would have led to additional social benefits of $8 billion per year over the last decade. The inability of the program to adapt to information about the marginal cost of emissions reductions that is revealed in the allowance price is an important flaw as cap-and-trade has been implemented to date in environmental policy.

Regulatory History of NO_x

According to environmental and public health economics (U.S. EPA 1998), the greatest economic impact from NO_x emissions stems from their contribution to the formation of secondary particulates concentrations and the resulting risk to human health. However, the driving forces behind NO_x emissions regulation have been concern about its contribution (along with SO_2) to the problem of acid rain and its contribution to the nonattainment of air quality standards for ozone. Titles IV and I of the 1990 Clean Air Act Amendments, respectively, addressed these concerns by regulating NO_x emissions from coal-fired electric generators.[8] As with SO_2 policy, the shift toward market-based solutions to reducing NO_x emissions evolved over time, specifically in response to the challenge of reducing ozone.

Title I addressed ozone concentrations by requiring states to promulgate emissions rate limits for large point sources of both NO_x and VOCs in regions not in attainment with the air quality standards for ozone. Title I emissions rate requirements are almost identical to those under Title IV for acid rain, but they included more immediate deadlines and provided less compliance flexibility.[9] These efforts helped to achieve reductions in ozone concentrations, but

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[8] While constituting the primary stationary source of NO_x, the electricity sector contributes only 22 percent of total U.S. NO_x emissions.

[9] Some state regulations also had averaging provisions similar to those provided under Title IV.

30 of the 98 regions that violated the ozone standard in 1991 continued to do so from 1998 to 2000, while 6 additional areas fell into nonattainment.

The Los Angeles basin is one area that finds considerable difficulty in attaining the ozone standard. The basin is particularly susceptible to ozone formation due to surrounding mountains and warm temperatures that create an atmospheric inversion layer that traps ozone in the basin. Fears about the inability to achieve the ambient ozone standard solely with prescriptive measures motivated the South Coast Air Quality Management District to start the first large urban cap-and-trade program for NO_x in 1994.[10] This program is known as the REgional Clean Air Incentives Market (RECLAIM).

Another area that had difficulty achieving the air quality standards was the Northeast. One element of the ozone problem in the Northeast and elsewhere is long-range transport of pollutants away from their emissions source. Atmospheric modeling has demonstrated that the formation of ozone in nonattainment areas is largely seeded by NO_x emissions generated elsewhere. Meeting the air quality standards for ozone with emissions rate limitations alone was challenging not only because of the transient nature of NO_x and ozone but because out-of-state sources of NO_x could not be directly regulated or included in state-level Title 1 compliance plans. Because of this, Congress created the Ozone Transport Commission (OTC) for the northeastern states under Title I to develop NO_x and VOC emissions rate standards for point sources. Recognizing that the emissions rate standards would not be sufficient for ozone compliance, the states agreed to implement a trading program for large sources of NO_x emissions in order to achieve further reductions. Trading under the OTC NO_x Budget Program began in 1999 and regulated emissions from May 1 to September 30, the season when conditions for ozone formation are most favorable.

Meanwhile, other regions of the country also faced continuing difficulty attaining the ozone standard in part because of their inability to control upwind NO_x emissions. 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. The process ultimately was unsuccessful, but it contributed a basis of information upon which the EPA implemented a

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[10] The program 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 NO_x trading programs have been adopted in Texas.

broader seasonal emissions trading plan in 2003 known as the NO_x Budget Trading Program (NBP), established under the NO_x State Implementation Plan (SIP) Call Program. The NBP, which affects point sources in 19 eastern states, including the northeastern states, was ultimately expanded to include 20 states. This program is modeled on the OTC NO_x Budget Program but requires greater NO_x reductions. CAIR, which was promulgated by the EPA in 2005 and took effect for NO_x in 2009, further expanded the seasonal NO_x trading program to 25 eastern states. It also added an annual NO_x trading program that includes a slightly different group of 25 states. The regulatory future of the CAIR program remains uncertain.

The following section describes these three market-based programs and discusses the environmental effectiveness, market performance, and cost savings of each. Where appropriate we also discuss technological innovation. The final section concludes with a discussion of the future under CAIR and potential U.S. climate policies.

NO_x Trading Programs

RECLAIM

RECLAIM, the first large-scale urban regional cap-and-trade program for NO_x, supplanted 40 existing prescriptive NO_x standards. It had the goal of reducing emissions from about 390 facilities by 8 percent per year from 1994 through 2003, a total emissions reduction of 70 percent from business as usual.

The trading market involves a heterogeneous mix of sources across two zones, and sales of emissions allowances between zones are allowed to go in only one direction so that the implicit shift in emissions does not contribute to downwind pollution. A RECLAIM trading credit allows the holder to emit one pound of NO_x. The compliance period is annual, with overlapping cycles so that some sources report emissions from January to December and others from July to June. Sources are provided allowances that may only be used in the compliance year they are allocated. This prohibits a firm from banking its allowances for future use. However, because of the overlapping cycles the program has encouraged the effective borrowing and banking of emissions allowances within a six-month window (Holland and Moore 2008).

At the outset, firms were able to choose the baseline year between 1989 and 1992 upon which their initial emissions allocation was determined. This was a period of high economic activity, providing a high baseline upon which to measure emissions. However, because of a regional decline in economic activity in the first years of the program and the inability to bank allowances, there was an ample surplus of emissions allowances that expired unused. There were few real emissions reductions, low allowance prices, and little trading of the early year vintages (Klier et al. 1997). In fact, the air quality management district 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 price of a NO_x credit began to rise from $1 to $30 and meaningful trades began to take place. This tightening of the NO_x market had been anticipated because the declining cap was expected to make economical the installation of postcombustion controls, including selective catalytic reduction (SCR), about that time. However, coincident with this transition in the NO_x market was an abrupt increase in allowance demand from electricity producers due to the flawed deregulation plan in California coupled with a drought that reduced electricity generation from hydroelectric facilities.[11] Less frequently used facilities and those that might install SCR were pressed into service and kept in service to meet this demand. By the spring of 2001 NO_x credits were trading at over $60 as demand for allowances substantially outpaced supply. In that year electricity generators were allocated 2,350 tons of credits (14 percent of the total allocation), purchased about 2,250 tons of credits, but emitted 1,100 tons over their total allowance holdings (Coy et al. 2001; Ellerman et al. 2003). Consequently sources began to fall into noncompliance. This is the only experience we are aware in which an emissions cap within a cap-and-trade program has been breached.[12]

These events precipitated significant changes to RECLAIM. In May 2001, the air quality management district removed the electricity generators from the RECLAIM market and required them to install pollution control technologies. In addition, all sources emitting over 50 tons were required to submit binding compliance plans in 2002 that described how the sources would comply with RECLAIM through 2006.

In 2005, the district adopted provisions that brought the electricity generators back into the RECLAIM market. To address spikes in allowance prices, the new changes included a provision specifying that if prices go above $7.50 per pound, the district could decide to increase

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[11] In 2000 the allocation of allowances in the RECLAIM SO_2 market also fell below historic annual emissions, but there was no dramatic price spike in this market. This is attributable to the absence of electricity generators in the region from the SO_2 market, because the electricity plants in the region use natural gas and light oil.

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

annual allocations (up to 2004 levels) in the following year. In addition, the total annual allocation was reduced by about 20 percent from the 2004 level during the 2007 to 2011 period (Fowlie et al. 2009). Sources may petition the district for an exemption from the additional allowance reductions based on their adoption of stringent abatement controls. However, to maintain the cap, 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.

One way to help avoid the spike in prices in RECLAIM would have been to allow allowance banking. Had banking been allowed, sources with low-cost abatement options would have had an incentive to adopt them early and retain the allowances for future periods. Banking gives sources a greater incentive to think about their long-term position in the market. In retrospect, 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 to eliminate banking. Burtraw et al. (2005) suggest that in addition, the decision in 2001 to pull the electricity generators out of the market and require future compliance plans could have been addressed differently. For example, a preannounced fee on emissions in excess of allowance holdings could have been charged.

Estimates of cost savings are undermined because of the difficulty of establishing a counterfactual baseline. Some early predictions of cost savings from the program predicted that compared with command-and-control regulation, it would cost firms about 58 percent less over the first six years of the program, for a total savings of $347 million (1987$) (Johnson and Pekelney 1996). It was also shown that the RECLAIM option would likely cause less disruption in the labor market than the command-and-control policy.

To evaluate the environmental effectiveness of RECLAIM, some authors have evaluated whether RECLAIM met its stated emissions reduction goals. Until trading in the RECLAIM program was suspended in 2001, emissions reduction targets were achieved, and evidence suggests that there was no distinct shift in the geographic distribution of emissions (Luong et al. 2000; Fowlie et al. 2008). Similar to estimates of cost savings, estimates of RECLAIM’s effect on emissions reductions have been highly dependent on assumptions about what emissions and compliance rates would have been under counterfactual command-and-control regulation (Stavins 2007; Green et al. 2007). However, matching firms in the Los Angeles basin under RECLAIM to firms subject to command-and-control regulations in other nonattainment areas, Fowlie et al. (2009) demonstrate that emissions at firms complying with RECLAIM were on average, 24 percent lower than those outside the program.

OTC NO_X Budget Program

The OTC consists of 11 member states that include the northeastern and midatlantic 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 implemented the preexisting emissions rate standards required by Title I of the 1990 Clean Air Act. These standards were expected to be achievable by using reasonably available control technology (RACT), which is a relatively modest technology standard compared to some others, such as "best available." In this stage, regardless of the allowances a source held, it could not emit above the level expected if using RACT. The second phase of the plan marked the beginning of the cap-and-trade policy that ran from 1999 to 2002.[13] The third phase was to begin in 2003 and require a tightening of the emissions cap to 70 percent below the five-month summer emissions of 490,000 tons in 1990. As described above, the third phase of this program was scrapped once the federally managed NBP was in place.

Unlike the RECLAIM program and the SO_2 trading program, the OTC NO_x Budget Program allowed for a variety of state programs and required a high level of coordination among them. 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. Each state then had discretion as to how it allocated its share of the total cap, its "budget," to its affected sources. Allowance allocation mechanisms and special programs that provided additional allowance allocations for the adoption of specific technologies varied greatly across states.

The engagement of the states was clearly important to the development of the OTC NO_x Budget Program (Farrell 2001). However, the EPA also played an important facilitating role. 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, drawing on

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[13] An original proposal for the OTC NO_x Budget Program envisioned three regions with constraints on trading between regions. In light of results of a market simulation model suggesting that such constraints were unnecessary, a unified market was adopted instead.

experience from implementing the SO_2 trading program (Donovan et al. 1997; Schary and Culligan 1997).

An important challenge faced by regulators of the OTC NO_x Budget Program was how to provide affected sources flexibility through banking while preventing spikes in emissions from rapid use of banked allowances, especially during atmospheric episodes with high temperatures when electricity demand and ozone levels would already be high. As a compromise, the trading program adopted progressive flow control, a unique constraint on banking that limited the number of allowances that could be withdrawn from a source's allowance bank (rather than the number of allowances that could go into the bank). Flow control limited the allowances that could be withdrawn to one allowance for every ton of emissions. After withdrawals exceeded this one-to-one balance, additional reductions were subject to a discount of two allowances per ton of emissions. Flow control was triggered when a regional bank grew to equal at least 10 percent of the total allowances allocated in that area.

Overall, reductions from the OTC NO_x Budget Program reflect a 54 percent decrease from the states' five-month summer 1990 baseline of 417,444 tons. Swift (2004) finds little geographic shifting in emissions, as emissions reductions in most states (especially large ones) were close to the average of 11 percent. Slightly greater emissions reductions occurred in New England, while emissions were slightly higher in Maryland. Emissions reductions in the western part of the region were equivalent to the reductions in the east. Moreover, Swift (2004) finds that the largest emitters before the program was implemented had disproportionately large reductions in emissions, suggesting that areas most greatly affected by NO_x emissions have realized the greatest benefits. There also is encouraging evidence that trading did not create temporal hot spots. Swift shows the program resulted in lowering NO_x emissions both in total and on high-emissions days, and Farrell (2003) shows specifically that average and peak emissions were lowered in equal proportion.

While trading under the 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).[14] There were other delays in the adoption of state rules and the timing of their adoption that led to market uncertainty.

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. When it was recognized that operational strategies exceeded performance expectations, it became apparent that there were significantly more allowances than emissions, and prices in the summer of 1999 dropped substantially (Farrell 2000). By the end of the 1999 season so many allowances were banked that flow control was triggered.

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

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, the price of allowances fell as it became clear that the NBP would replace the OTC NO_x Budget Program. As part of the NBP, the EPA made available a pool of allowances that states could use to reward early reductions. Most of the OTC states exchanged a portion of allowances from this “compliance supplement pool” for banked OTC allowances, but the total pool allocated to the states participating in the OTC program was less than 25,000 allowances, so only a portion of the banked allowances was carried forward to the NBP. Discretion was left up to the states to decide whether to reward banked allowances, and all states did so. Nonetheless, these provisions preserved some of the value of banked allowances from the OTC program. The size of the bank actually increased from

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[14] Two utilities initiated a legal challenge to 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.

43,585 in 1999 to an estimated 91,000 allowances in 2002, and prices remained well above zero (U.S. EPA 2003).

NO_x Budget Trading Program under the NO_x SIP Call

In late 1997, under Section 110 of the 1990 Clean Air Act Amendments, 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 SIPs, which outline their strategies for complying with federal ambient air quality standards. The NO_x SIP Call assigns each state a summertime NO_x emissions budget for large point sources. 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, the NBP. Other similarities of the NBP to the OTC NO_x Budget Program include the flexibility of the states to determine how their budgets should be allocated and the flow control restrictions on banking. Rather than initiate the third phase of the OTC NO_x Budget Program, states in the OTC region chose to comply with the SIP Call restrictions through the NBP starting May 1, 2003.

An additional 11 states throughout the Midwest and South were slated to comply with the SIP Call on May 1, 2003, as well.[15] Litigation delayed their participation in the NBP until May 24, 2004, one month into the 2004 ozone season. Sources in the eastern part of Missouri later came under the NBP in 2007. All told, 20 affected states chose to participate in the NBP to meet the NO_x SIP Call (Figure 2).

Beginning in 2009, CAIR created a broader ozone season NO_x cap-and-trade program in which states could participate to achieve their NO_x SIP Call requirements. In contrast with the NBP, CAIR stretched west to include 25 total states plus the District of Columbia under a seasonal program, and a slightly different set of 25 states in an annual program. All NBP seasonal state budgets for NO_x emissions remained at least as stringent under CAIR, although some were tightened. All NBP states except Rhode Island opted into the new ozone season NO_x trading program under CAIR. All NBP allowances banked in 2009 (275,367 in total) were transferred to the CAIR program and flow control was removed (U.S. EPA 2009b). All

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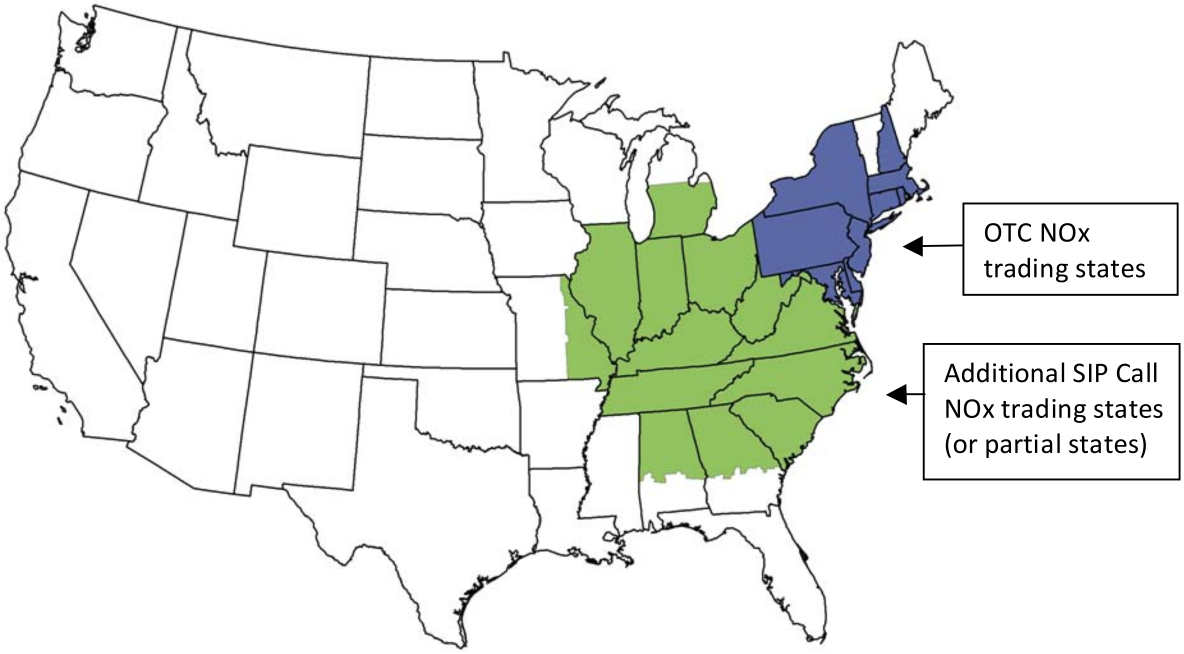
[15] These states include Illinois, Indiana, Kentucky, North Carolina, Ohio, South Carolina, Tennessee, Virginia, and West Virginia and portions of Alabama and Michigan.

allowances previously banked under the NBP can be used to comply with the CAIR NO$_x$ ozone season cap at any time on a 1:1 basis.

The NBP helped lead to an overall 62 percent reduction in summertime NO$_x$ emissions within its region from 2000 through 2008 (U.S. EPA 2009b). Concentrations of ozone averaged over eight-hour intervals decreased in all states participating in the NBP by 10 percent between the years 2002 and 2007 (U.S. EPA 2008). This percentage includes an adjustment made for meteorological conditions that aid in the formation of ozone. Spatially, a strong correlation has been shown between decreases in ozone concentrations in areas downwind of decreased NO$_x$ emissions (U.S. EPA 2008).

Figure 2. OTC NO$_x$ Budget Program and SIP Call NO$_x$ Trading States



Source: www.epa.gov/airmarket/progress/docs/otcreport.pdf.

Like the OTC NO$_x$ Budget Program, the NBP experienced a large rise and then decline in the allowance price during its first season, the most dramatic shift to date noted in the market for NO$_x$ allowances (U.S. EPA 2009a). The prices for 2003 and 2004 allowances were fairly even leading up to the 2003 trading season. 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).

After these early price highs, allowances traded at lower and lower prices throughout the rest of the NBP. For example, 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 summer weather and the expectation that many allowances would be banked. The large allocation in 2004 contributed to continued growth in the bank. During the four-year period from 2005 through 2008, flow control was triggered and allowances prices gradually declined. At the start of the 2006 compliance period, prices for allowances were roughly $2,725 but dropped to $900 by the end of the year and stayed between $500 and $1,000 throughout 2007 and into 2008 (U.S. EPA 2007, 2008, 2009b). In 2008 NO_x allowance prices jumped to a high of $1,413 just after courts vacated CAIR, and dropped to $592 at the close of 2008, the last year of the NBP (U.S. EPA 2009b). This closing cost reflects the minimum operating cost of existing SCRs; at lower prices, SCRs might be taken out of service, and this would lead to an increase in the allowance price. Thus the operating cost of SCR serves as an effective price floor, and the triggering of this floor highlights the market's reaction to regulatory uncertainty. Moreover, this price is below the expected cost of new capital to meet CAIR requirements (U.S. EPA 2009b). Another sign of the contraction of the NBP market in its later years can be seen in the decline in trades between economically distinct parties; in 2005 these made up 30 percent of all trades, but by 2008 they comprised only 25 percent (Napolitano et al. 2007; U.S. EPA 2009b).

In addition to the emissions reductions and market dynamics of the NBP, other important features include the technological innovation it spurred, the cost of compliance (and secondarily of electricity), and the overall net benefits of the program.

Technological innovation under the NBP took the form of extensive small-scale modifications to existing capital that likely would not have occurred under command-and-control regulation. Linn (2008) estimates that 10 to 15 percent of emissions reductions were the product of such modifications. The rest of the reductions can be explained by fuel switching and the retirement of noncontrolled units. Significant drops in coal and oil heat input to power plant combustion were supplanted by a 65 percent increase in natural gas heat input from 2003 to 2008. Nearly 70 percent of plants retired over the same time period were noncontrolled units (U.S. EPA 2009b).

The cost to comply with the NO_x SIP Call program through the NBP was estimated by Burtraw et al. (2001) at $2.1 billion (1997$) per year. EPA's analysis finds that the average cost per ton reduced would be $1,807 (U.S. EPA 1998), but it does not provide an estimate of the marginal cost, which would translate into the expected allowance price.[16] EPA (1998) predicts a change in electricity prices of about 1.6 percent, assuming market-based pricing throughout the electricity sector, and about 1.2 percent, assuming traditional regulated pricing. Ex post estimates of the actual change in electricity prices have been unsatisfactory because the period was marked by substantial variation in relative fuel prices, which dominated the change in costs associated with emissions compliance.

Lastly, the most telling metric for evaluating the program would be net benefits (benefits minus cost) as well as the cost-effectiveness of the program. Both are significantly affected 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, like that proposed under CAIR, 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).[17]

Recent Changes in the SO_2 and NO_x Markets

The emissions allowance markets have been buffeted by two major policy considerations: CAIR and climate change. Both of these introduce substantial uncertainty with respect to control of SO_2 and NO_x.

CAIR established three cap-and-trade programs to lower SO_2 and NO_x emissions in the Northeast: annual programs for SO_2 and NO_x emissions to combat $PM_{2.5}$ (fine particulate matter with an aerodynamic diameter of up to 2.5 μm) and a summertime NO_x emissions cap to target ozone (Figure 3). All were designed to be implemented in two phases. The first phase of both

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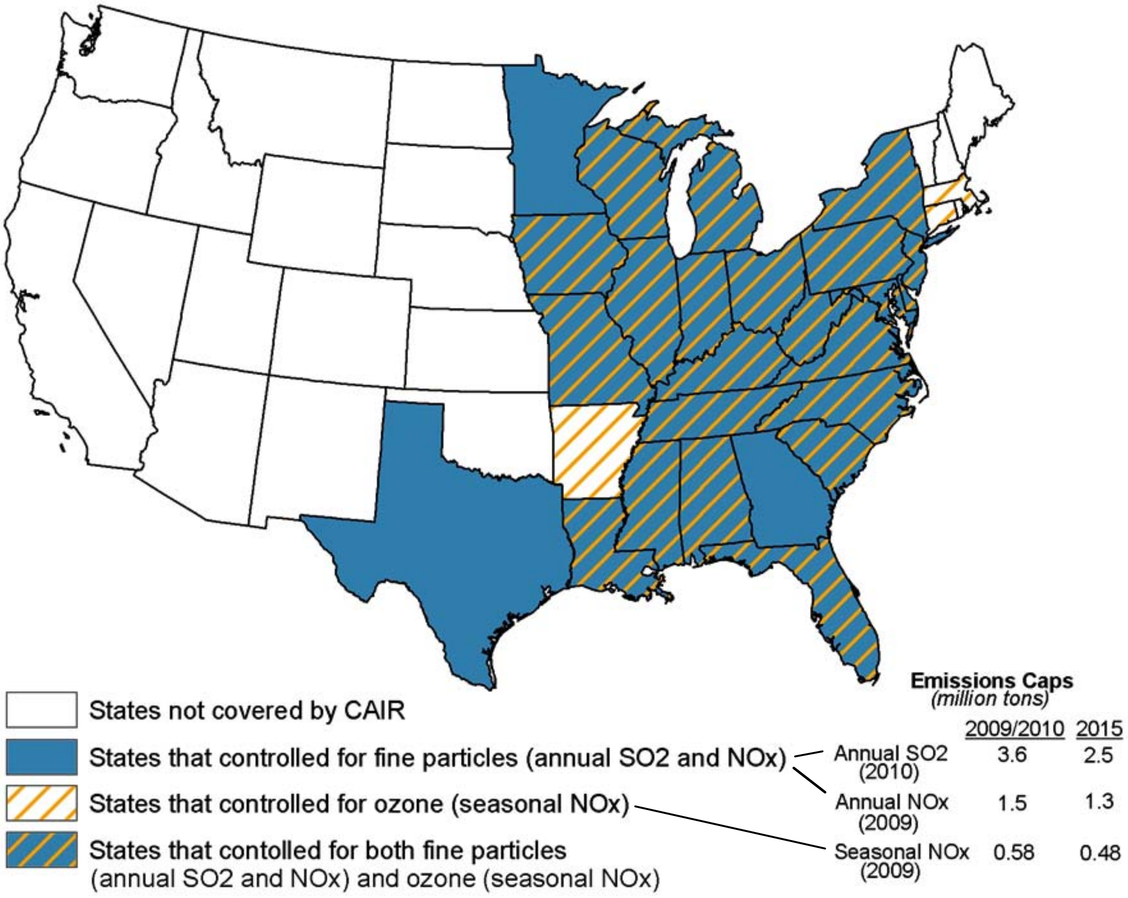
[16] The EPA model assumes that controls installed in response to emissions standards under Titles I and IV are the only existing controls in the Ozone Transport Region (OTR) for its analysis; Burtraw et al. (2001) use the OTR trading policy and its lower average emissions rates as their starting point. 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).

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

NO_x programs began in 2009 and that for SO_2 will begin in 2010. The second phase for each of the three programs is scheduled to begin in 2015.[18]

Figure 3. CAIR SO_2 and NO_x Programs



Source: www.epa.gov/airmarkets/presentations/docs/epri07/cair_camr_update.ppt.

When the Court of Appeals for the District of Columbia vacated CAIR on July 11, 2008, the SO_2 emissions allowance price fell from \$315 to \$115 in one day (ICAP Energy 2009). The response in NO_x markets was similar; prices for annual NO_x allowances fell from nearly \$5,000

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[18] CAIR was originally intended to be accompanied by a similar trading program for emissions of mercury under the Clean Air Mercury Rule (CAMR). However, the Courts vacated the CAMR ruling on February 8, 2008, and unlike CAIR, CAMR was not remanded to the EPA for revision. Since this ruling, power plants are no longer on the Clean Air Act list of sources of hazardous air pollutants.

to just above $1,000 per ton in a short time. The court vacated the rule for two major reasons: first, that upwind emissions would not be minimized adequately due to the vagaries of an emissions market with trading, and second, that the EPA did not have the authority to assign allowance values in the case of the SO_2 market. Industry reacted with concern; it had made substantial investments to be ready for implementation of CAIR, and the logic of those investments was undermined by its removal. Moreover, the underlying environmental problems with respect to particulate matter and ozone remained, and absent a trading program to address these problems industry could expect less flexible regulatory standards to come from the EPA.

The widespread view among industry and Congress, not to mention environmental advocates, was that the court had gone too far. This set the stage for a subsequent decision in December 2008 that reinstated the rule but also remanded the rule back to the EPA for adjustments to address the concerns of the court. This court decision pushed annual NO_x prices to $6,000 per ton in December 2008, but ongoing uncertainty has contributed to a gradual decline to near $2,000 per ton. SO_2 prices have not yet recovered. Meanwhile, a process is moving forward at the EPA to revise the rule, and there is activity in Congress to codify the rule as statute.

There is strong evidence of the close connection between regulatory uncertainty and structural shifts in allowance market prices. The introduction of CAIR corresponds to an SO_2 market price spike from 2005 through 2006, and the uncertainty associated with the Court's decisions corresponds to an all-time SO_2 allowance price low in 2009. To a lesser degree, NO_x NBP market prices fluctuated in 2008 in response to legal and regulatory uncertainty. These structural market shifts can limit the cost savings associated with cap-and-trade and can lead to inefficient levels of pollution. A potentially useful form of market reform would be the introduction of mechanisms to insure that prices neither fall too low nor rise too high. A price collar or symmetric safety valve can perform this function. In particular, a price floor would help ensure the value of investments to reduce emissions and also help to capture additional emissions reductions when prices fall below expected levels.

The ultimate source of uncertainty in the long run is the development of climate policy. Most analyses of pending legislation in the United States indicate a substantial reduction in coal-fired electricity generation over the next few decades, at least until carbon capture and storage technology might become commercially available. The reduction in coal generation would correspond with a reduction in SO_2 and NO_x emissions. CAIR affects SO_2 emissions in the 25 states that are responsible for the vast majority of coal-fired electricity generation. Between 2010 and 2014, CAIR would require the surrender of two Title IV allowances per ton of SO_2 emissions in this 25-state region, and 2.86 allowances per ton thereafter. If all emissions occur in this region, it would result in annual emissions of 3.13 million tons per year after the bank is entirely drawn down. Analysis (U.S. EIA 2009) of the only federal climate legislation to pass through the U.S. House of Representatives (H.R. 2454, introduced by Congressmen Waxman [D-CA] and Markey [D-MA]) indicates that electricity sector emissions for the nation, the vast majority of which would be in the CAIR region, would remain above this level through 2028. Hence, the SO_2 market would be expected to survive with a positive allowance price under U.S. climate policy. Recent legislative proposals, including one by Senator Carper (D-DE), would reduce the SO_2 cap to 1.5 million tons per year in 2015 and below this level after 2020, at the discretion of the EPA administrator. If this proposal were to take shape in legislation it would be likely to preserve a long-term role for the SO_2 market.

Electricity sector emissions of NO_x are estimated under Waxman–Markey climate legislation to be 2 million tons per year in 2020, falling to 1.5 in 2027 and to 1.0 in 2030 (U.S. EIA 2009). The annual NO_x cap affects a 25-state CAIR region and is set at 1.5 million tons per year, declining to 1.3 million tons in 2015. Because the seasonal NO_x cap affecting a slightly different 25-state region is less likely to be affected in a similar manner, NO_x markets also could be expected to survive with a positive price into the future under climate policy. Senator Carper's proposal would regulate NO_x emissions nationally in two regional zones. The western region would be capped beginning in 2015 at 320,000 tons of NO_x, and the eastern region would be capped at 1.3 million tons. After 2020 these amounts could be reduced further at the discretion of the EPA administrator. These changes would bolster the NO_x market even further.

In summary, the future for the SO_2 and NO_x markets in the United States looks bright. The issue is whether we can get to the future. Uncertainty about implementation of CAIR has turned the management of SO_2 and NO_x allowances into a game of chance. In the long run uncertainty about climate policy may be even more important. In the absence of legislation establishing a cap-and-trade program for CO_2, the EPA is likely to take regulatory action to reduce CO_2 that will have a direct bearing on the operation of power plants and consequently on the performance of the markets for SO_2 and NO_x.

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