The Paparazzi Take a Look at a Living Legend: The SO_2 Cap-and-Trade Program for Power Plants in the United States

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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 (CAAA) presents the first real test of the wisdom of economists' advice. This paper provides an overview of the origins, design, and performance of the U.S. acid rain program, and an analysis of its specific features and its adaptability as a model for addressing other pollution problems, such as control of NO_X or CO_2 emissions. The program also has resulted in innovation through changes in organizational technology, in the organization of markets, and through experimentation at individual boilers, much of which arguably would not have occurred under a more prescriptive approach to regulation. There is ample evidence that allowance trading has achieved substantial cost savings, and there are lessons that can guide the design of future policies.

Key Words: emission trading, cap and trade, air pollution, cost-benefit analysis, electricity, particulates, sulfur dioxide, SO_2, health benefits, acid rain

JEL Classification Numbers: Q25, Q4, D62, Q28

Contents

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Introduction

For years economists have urged policymakers to use market-based approaches such as cap-and-trade programs or emission taxes to control pollution. In 1990, the cap-and-trade approach to managing pollution finally hit marquee status with passage of the Clean Air Act Amendments and implementation of the sulfur dioxide (SO_2) emission allowance trading program. The SO_2 allowance market presents the first real test of the wisdom of economists' advice.

Title IV of the 1990 U.S. Clean Air Act Amendments (CAAA) regulates emissions of sulfur dioxide (SO_2) from electricity generating facilities under an emission trading program that is designed to encourage the electricity industry to minimize the cost of reducing emissions. The industry is allocated a fixed number of total allowances, and firms are required to surrender one allowance for each ton of sulfur dioxide they emit.[1] Firms may transfer allowances among facilities or to other firms, or to 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, set at about one-half the amount emitted in 1980. The cap accommodates an allowance bank, so 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 that has accrued from previous years.

The program combines a solid environmental goal, in the form of a cap on the annual allocation of emission allowances, with the flexibility to trade or bank allowances. Rather than forcing firms to emit SO_2 at a uniform rate or to install specific control technology, emission

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1 Allowances are allocated to individual facilities in proportion to fuel consumption during the 1985–1987 period multiplied by an emission factor. About 2.8% of the annual allowance allocations are withheld by EPA and distributed to buyers through an annual auction run by the Chicago Board of Trade. The revenues are returned to the utilities that were the original owners of the allowances.

allowance trading is intended to enable power plants operating at high marginal pollution abatement costs to purchase SO_2 emission allowances from plants operating at lower marginal abatement costs. Such trading, by equalizing marginal abatement costs among generating units, should limit SO_2 emissions at a lower cost than traditional command-and-control approaches.

This paper provides an overview of the origins, design, and performance of the U.S. acid rain program and analyzes its specific features and its adaptability as a model for addressing other pollution problems, such as control of NO_x or CO_2 emissions.[2] The next section provides further background on the regulation of SO_2 emissions from coal-fired power plants. Subsequently, we describe Title IV in more detail and survey the *ex ante* and *ex post* estimates of the costs of the program. Finally, we offer conclusions, drawing on a set of hypotheses that are common to the case studies addressed in this project, and looking to the future of SO_2 regulation.

2. Background

Sulfur dioxide is a ubiquitous threat to the environment and public health. Along with nitrogen oxides (NO_x), SO_2 is a precursor to acidic particulate matter that contributes to the acidification of ecosystems (acid rain).[3] Related to acidification are potential secondary impacts on the amounts of aluminum and methylmercury in lakes and fish.

As a gas emitted directly from power plants, SO_2 is also regulated as a criteria air pollutant affecting human health. Increasingly, however, the most important role of SO_2 from the standpoint of public health is its role as a precursor to secondary particulates, which are a constituent of particulate matter (PM), another criteria air pollutant. SO_2 and PM are associated with morbidity and mortality effects.

In areas that had not attained national ambient air quality standards (NAAQS), states are required under the Clean Air Act to develop implementation plans to demonstrate reasonable progress toward the NAAQS. Typically, these plans include regulation of existing sources. In the 1970s many areas were in nonattainment for the local SO_2 NAAQS standard, and this

[2] See also Ellerman, 2003.

[3] Of the two contributors to acid precipitation, sulfur dioxide is considered the more significant factor because most affected regions still have significant capacity to buffer excess nitrogen. In the future, nitrous oxide emissions may rise in significance depending on the region's soil characteristics. See discussion in Acid Deposition Standard Feasibility Study: Report to Congress (U.S. EPA, 1995, p. 56).

nonattainment status was the basis for the establishment of emission rates to protect human health based on ambient air quality within the vicinity of a power plant. As part of the remedy for the contribution of SO_2 emissions to local air quality problems in the 1970s, 429 tall stacks, many over 500 feet tall, were constructed on coal-fired boilers in the electricity industry (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, and SO_2 is no longer widely perceived as a local health problem.

However, the remedy to local air quality problems for SO_2 contributed to the undoing of air quality at a regional level. Emitted high in the atmosphere, SO_2 emissions from coal plants travel hundreds of miles and convert to sulfates that, as particulates, play an important role in air quality affecting human health and visibility. Deposition of sulfuric compounds in soils and waterways in regions distant from the source of emissions contributes to acidification of forests and lakes.

Although acid rain and secondary particulates are national problems, they are most severe in the eastern United States because most high-sulfur coal is found in the Appalachians and the Midwest. Western coal, such as that found in the Powder River Basin, located in Wyoming and Montana, is mostly low-sulfur coal. The cost of transportation is a significant part of the delivered cost of coal, and coal-fired power plants, which are located predominantly east of the Mississippi River, have tended to burn local high-sulfur coal. This is reinforced by political forces, as states have encouraged utilities to burn high-sulfur coal to protect in-state coal mining jobs, and by weather patterns that blow airborne emissions largely from west to east.

New Source Performance Standards

The 1970 amendments to the Clean Air Act implemented performance standards for *new sources*, as well as those that undertake a major modification, based on emissions per unit of heat input. Collectively, these standards are known as New Source Performance Standards (NSPS). The first generation of NSPS was an emission rate standard of 1.2 pounds of SO_2 per million Btu of heat input at a facility. This standard eventually became a touchstone for the allocation of allowances under Phase II of the SO_2 trading program.

The NSPS were amended in 1977, and since taking effect in 1978, new coal-fired power plants have faced an emission rate-based standard that requires a 90% reduction in SO_2

emissions from uncontrolled levels, or 70% if the facility uses low-sulfur coal.[4] This approach essentially required scrubbers, the only available technology that could achieve such reductions, and essentially eliminated compliance through the use of process changes or demand reduction. Although the emission limitation was nominally a performance standard, it effectively dictated technological choices in a typical command-and-control fashion. Operators of new facilities could not switch to cleaner fuels to achieve comparable emission reduction, and the only technology available to meet the standard was scrubbing. Given the requirement to install scrubbers, the NSPS reduce or eliminate the incentive for new plants to use low-sulfur coal.

The NSPS are seen as a way to improve environmental performance over time. However, the fleet of power plants that existed before these standards seems to have an almost indefinite life, which many have argued has been lengthened by their cost advantage relative to new sources that face NSPS. (Ellerman 1998; Nelson et al. 1993) As a consequence, NSPS have been an ineffective tool for addressing emissions of SO_2 from existing coal-fired plants.

Hence, prior to the 1990 CAAA, there was uneven treatment of coal-fired facilities. New sources faced tough standards, but this may have contributed to the extension in the operating life of existing facilities. Meanwhile, existing facilities were regulated only with respect to local air pollution, even though they make a significant contribution to regional problems. The SO_2 program bridges this gap by regulating SO_2 emissions from all new and existing power plants in a uniform and cost-effective manner.[5]

Political Preconditions for the "Grand Experiment"

In the 1980s more than 70 pieces of legislation were proposed to deal with the issue of SO_2 emissions and associated environmental problems. One prominent proposal in 1983 sought to rollback emissions by 10 million tons from 1980 levels, about the same amount as eventually required under Title IV, by requiring the installation of scrubbers (flue gas desulfurization equipment) at the fifty dirtiest plants that represented 89% of the nation's pre-New Source Performance Standard coal-fired capacity.[6] The estimated levelized cost of this proposal ranged from about $7.9 billion per year ($1995), according to government studies (OTA 1983), to $11.5

[4] The change in the NSPS that followed the 1977 Clean Air Act Amendments was promulgated in 1979 and made effective retroactively to September 18, 1978.

[5] It is important to note that the NSPS continue to be in force for new plants.

[6] Under the Sikorski-Waxman Bill in the 98th Congress (HR 3400), scrubbing would have been applied to about half of the affected capacity and accounted for 70% of the SO_2 reduction. The bill also would have required switching from high- to low-sulfur coal and other improvements at other facilities (Edison Electric Institute 1983).

billion per year ($1995), according to an industry study (Temple et al. 1983). An important part of this proposal was a fund that would have redistributed 90% of the capital cost for compliance to electricity consumers in utility systems or regions away from where emission reductions would be achieved.[7]

The debate over the cost of controlling acid rain, and the search for an alternative to forced scrubbing, culminated in Title IV of the CAAA of 1990. The "cap with trading" design enabled a compromise between environmental interests, which sought a 10 million or 12 million ton reduction in annual SO_2 emissions, and industry groups, which argued that such reductions would be prohibitively expensive.[8] The result is what has been called the "grand experiment" (Stavins 1998).

3. Program Design

Under Title IV, the annual allocation of allowances for SO_2 emissions from electric utility power plants are capped ultimately at 8.95 million tons, approximately 10 million tons less than the amount emitted by utility facilities in 1980.[9] Reductions to achieve the 8.95 million ton cap take place in two phases. Phase I began in 1995 and affected the 110 dirtiest coal-fired electricity generating facilities. Starting in 2000, Phase II covered all other facilities greater that 25 megawatts of capacity, plus smaller ones with a sulfur content of fuel greater than 0.05%.

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 emission rate calculated such that aggregated emissions equal the target emission cap. One SO_2 allowance entitles its holder to emit

[7] Another bill (H.R. 4567) in 1986 was aimed at similar environmental gains but promoted cost reductions by applying a target average emission rate for each utility company. It is noteworthy that an industry study suggested the costs would be higher as a result: although intrafirm trading would reduce scrubbing by 14% (to 74 gigawatts of capacity), it would increase reliance on low-sulfur coals, and the resulting premium on low-sulfur coal would raise costs for units already using low-sulfur coal (TBS 1986). This prediction is contradicted by the turn of events under Title IV, when the cost of low-sulfur coal fell with its expanded use. Taking account of changes in fuel and other input prices between 1983 and 1986, the study found that costs would be $7.5 billion per year. This can be compared with estimates of $3.5 billion to $6.2 billion, and of $3.4 to $4.3 billion by Office of Technology Assessment (TBS 1986; all estimates in $1995). Cost sharing through an industry fund remained a prominent provision of this proposal.

[8] For legislative histories, see Kete (1992) and Hausker (1992).

[9] Electric utilities in 1985 accounted for about 70% of SO_2 emissions from point sources in the United States.

one ton of SO_2. Other industrial sources are excluded from the mandatory program but they may voluntarily subscribe, after establishing a historical emissions profile.

To save costs, operators of affected facilities can trade emission allowances between their own facilities or with other firms. Hence, individual facilities can implement abatement measures that depart from an engineering prescription of the cleanest technological possibility for that facility. If a plant reduces its emissions below its endowed level of emission allowances, it can switch them to another of its units, bank them for future use, or sell them. If a plant emits at a level greater than its endowed level, it must compensate another plant or firm to reduce emissions commensurately. This provision allows for programmatic cost savings by creating incentives for the plants with the lowest costs of SO_2 reduction to make more of the reductions, thereby minimizing overall compliance costs.

4. *Ex Ante* Analysis of the SO_2 Trading Program

One of the earliest studies of the cost under an allowance trading system was Elman et al. (1990), who estimated the marginal cost of compliance and used this as the value of an emission allowance. Under a perfect trading market, this study predicted marginal costs (presumed to equal allowance prices under perfect trading) of $742 to $1,032 ($1995). Costs for imperfect trading (i.e., trading that did not equate marginal cost over the entire market, perhaps because of state constraints on the use of local coal) were estimated to average $1,935, ranging up to $2,580 or even $5,160 at several utilities. However, a more relevant study is ICF (1990), which was done for the Environmental Protection Agency (EPA) and available prior to enactment of the legislation. This study captured more accurately the ultimate design of the regulation and projected marginal costs of $579 to $760 ($1995) for full compliance under the program. This and a number of other studies are summarized in Table 1.[10]

In the 1980s, the federal government spent more than $500 million studying scientific aspects of the acid rain problem through an interagency effort called the National Acid Precipitation Assessment Program (NAPAP). That research informed the congressional debate but did not directly lead to the compromise that emerged. By 1990, there were few economic

[10] These estimates describe long-run costs that were expected to obtain when the allowance bank, which was expected to build up to about 11 million tons by the end of Phase I (in 2000), would be drawn down and net contributions to the bank would be zero.

estimates of benefits of reducing SO_2. In one study, NAPAP considered a change in acidic deposition in just New York and parts of New England; for coldwater recreational fishing alone, it estimated willingness-to-pay for improvements comparable to those expected to result from Title IV to be $4.2 million to $14.7 million.[11] The only economist we know of who ventured an opinion of the overall relative benefits and costs of Title IV in 1990 wrote that expected benefits and costs appeared to be about equal (Portney 1990).

5. The First Years of the SO_2 Trading Program

Two types of measures are most important in assessing the performance of the SO_2 trading program. One is its performance in achieving the goal of reducing emissions, and the related environmental and health benefits. The second is the cost of achieving these emission reductions and the extent to which potential gains from trading allowances have been realized. Related issues include the efficiency of allowance banking, the effects of the program on incentives for technical change, and the administration and compliance costs of the program. We address these issues in this section.

Emissions

The SO_2 provisions of Title IV have led to dramatic declines in emissions of SO_2 from electricity generators over the past 10 years (U.S. EPA 2002). During Phase I, actual SO_2 emissions fell dramatically relative to recent level, and although somewhat less dramatically, actual emissions also fell 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 30% below 1980 levels.

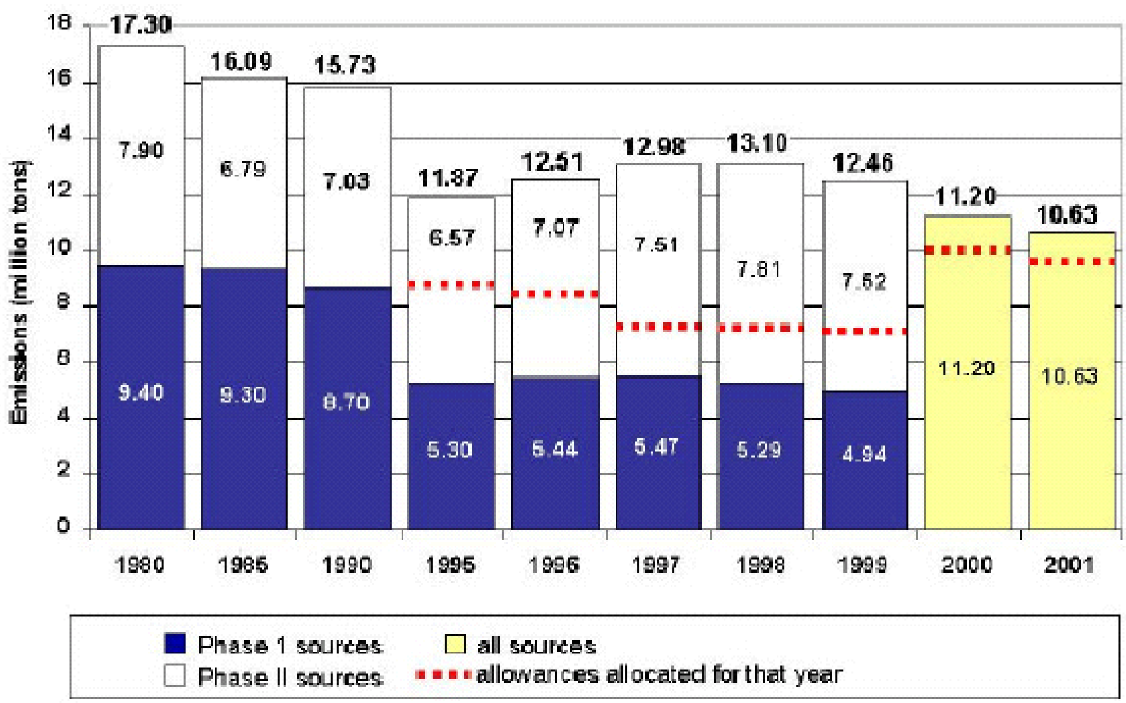
Phase I resulted in substantial overcompliance by Phase I units, with total emissions from these units falling well below capped levels throughout the Phase I period. These units surpassed the emission reduction goals of the program because they were allowed to bank unused emission allowances for use in future years. The unused allowances created by this overcompliance were added to a bank that totaled nearly 11.6 million allowances by the end of Phase I. Although emissions from the Phase I units remained relatively flat over the next four years, emissions from

[11] NAPAP (1991, p. 384) ($1989). This estimate omits indirect use and nonuse benefits.

Phase II units rose, causing total emissions to climb somewhat between 1995 and 1999. However, during the first year of Phase II, total SO_2 emissions declined further and continued to decline in 2001, reaching a level of 10.63 million tons—almost 40% below 1980 levels.

The ability to bank allowances for future use proved crucial to the 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.

Figure 1. SO_2 Emissions for Utility Sources 1980–2001



Source: U.S. EPA (2002).

During the two years after the beginning of Phase II in 2000, emissions exceeded the annual allowance allocations by roughly 1 million tons each year as utilities begin to draw down the bank. Emissions are expected to continue to be above the annual cap through the remainder of this decade as that number gradually declines to roughly 9 million tons per year. Nonetheless, despite drawdown of the allowance bank over the decade, emissions during the decade will be substantially below the levels predicted in the absence of Title IV. (U.S. EPA 2001).

Environmental Effectiveness

The environmental improvements associated with this decline in emissions also have been substantial. According to EPA, wet sulfate deposition (acid rain) in the eastern United States fell by as much as 25% during Phase I (U.S. EPA 2001).

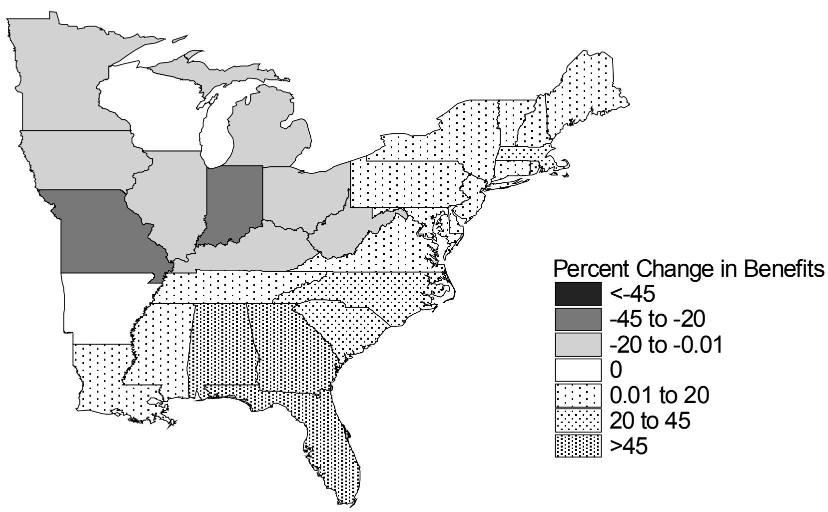
However, even though the SO_2 program's principal political motivation was the desire to reduce acid rain, the lion's share of the benefits are expected to come from improvements in human health. Air quality has also improved as ambient concentrations of sulfate particles (SO_4) have declined, especially in those areas where sulfate concentrations have historically been high. The human health benefits of these sulfate reductions are believed to be substantial. EPA estimates that by the year 2010, the total annual health benefits associated with SO_2 emissions reductions under the program will be more than $50 billion per year (U.S. EPA 2001). In an independent assessment, Burtraw et al. (1998) used an integrated assessment model developed on behalf of NAPAP to study the benefits and costs of Title IV regulations. They simulated both the environmental consequences and associated health benefits arising from the program's expected reductions in emissions of SO_2 and NO_x and the costs of reducing emissions and found that the human health benefits from particulate reductions alone are expected to be 7 times the costs of controlling emissions during Phase I. As emissions fall even further during Phase II, this ratio is expected to increase to at least 10 to 1 and even higher under more aggressive assumptions about future growth in electricity demand and power plant lifetimes. This is a startling change, compared with the only extant estimate, which in 1990 suggested benefits and costs were about equal. The difference stems from a greater understanding today of the expected benefits associated with particulate reductions, and the unanticipated low realized costs of emission reductions under the program.

The Effects of Trading on the Environment

Some observers have feared the SO_2 trading program might cause large regional shifts in emissions that might serve to concentrate pollution in "hot spots." Originally, the SO_2 trading program was designed with two trading regions, one in the East and one in the West, to make sure that emissions were adequately reduced where problems with acid rain were the most severe—in the East. Ultimately, the two-region model was abandoned and replaced by a single national 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). Some have argued that unfettered trading in a single national market is a mistake because it has failed to adequately protect sensitive areas in the Northeast, particularly in New York State (Solomon and Lee 2000).

However, despite these fears, the evidence points in the other direction. Burtraw and Mansur (1999) model the effects of allowance trading and banking under the SO_2 program within a simulation model and find that trading should be expected to lead to inconsequential, though positive, changes in the health-related benefits of the SO_2 program. Advocates have expressed strong concern that trading could lead to an increase in pollutant concentrations in heavily populated areas along the east coast of the United States. However, Burtraw and Mansur find that the entire eastern seaboard can expect benefits due to the expected pattern of trading, in addition to the aggregate decrease in emissions (Figure 2). Furthermore, they expect trading to contribute to decreases in acid deposition in sensitive regions.

Figure 2. Percentage Change in Title IV Baseline Benefits Attributable to Trading for 1995

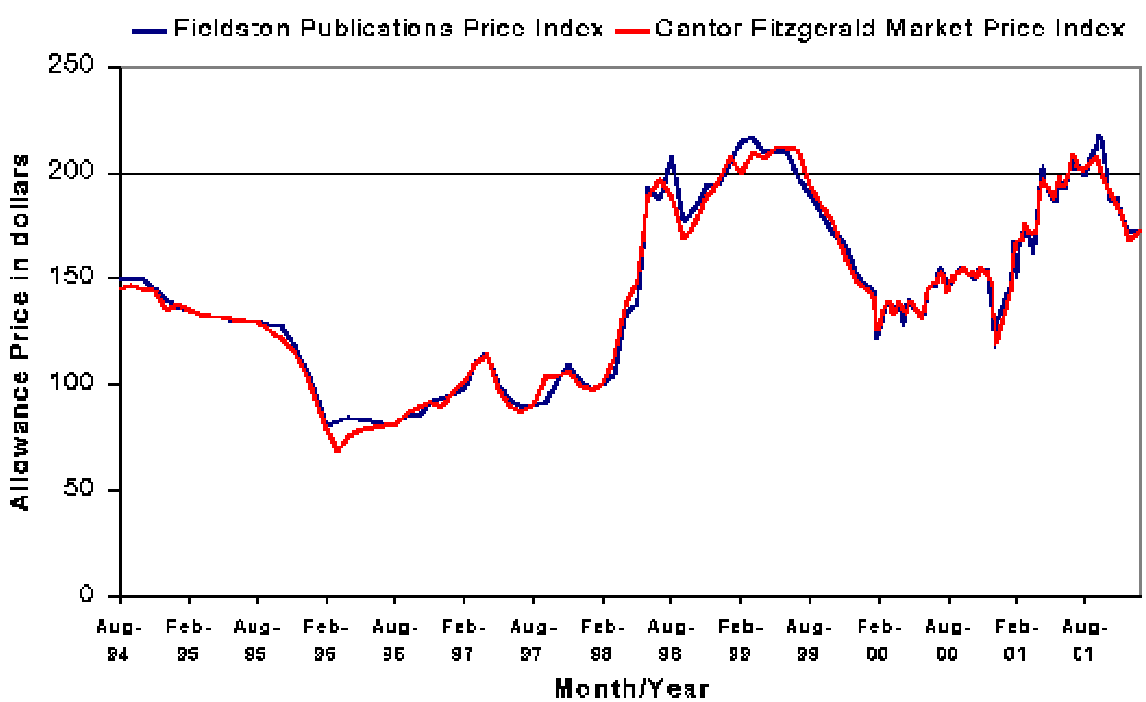


Swift (2000) argues that banking also has not generated hot spots. He shows that, largely as a result of allowance banking, emissions in virtually all states were below emission allocations from 1995 to 1998. Swift shows that during this four-year period, more than 80% of the allowances used to offset emissions came from the same state as the emitting source. Consistent with Burtraw and Mansur, he suggests that allowance trading may have served to cool potential hot spots as the Phase I plants with the largest emissions are the ones that have cleaned up the most. EPA's own analysis of the geographic shifts resulting from trading during each year of Phase I shows that sellers and ultimate buyers of SO_2 allowances tend to be located within 200 miles of each other (U.S. EPA n.d.). Finally, trades of SO_2 at a national level cannot lead to violations of local ambient air quality standards for SO_2 because sources must comply with local standards as well as with the national aggregate cap-and-trade program.

The Efficiency of SO_2 Allowance Markets

Allowance prices have fluctuated since trading under the program began. The price of an allowance started at close to \$150 per ton at the beginning of the program and fell to around \$70 by early 1996. During 1999 prices rose above \$200 per ton but fell again in 2000 to a point closer to \$150. Since the beginning of Phase II, allowance prices have fluctuated between roughly \$70 and \$210 per ton, with an average price during the period of close to \$170 per ton. Figure 3 illustrates allowance prices over time.

Figure 3. SO_2 Allowance Prices, 1994-2001



Source: U.S. EPA, http://www.epa.gov/airmarkt/trading/so2market/prices.html (accessed February 3, 2003).

One oft-cited measure of the success of the SO_2 allowance market has been the observation that allowance prices are substantially lower than predicted by EPA and others at the time the program was adopted (see Table 1). Both the former administrator of EPA and the former chair of the Council of Economic Advisers have suggested that *ex post* realized allowance prices are much lower than *ex ante* estimates of marginal abatement costs and that this fact demonstrates that the allowance trading market is responsible for reducing the costs of curbing SO_2 emissions.[12]

Allowance prices have been lower than expected *ex ante;* however, if used as a proxy for program costs, these differences are exaggerated.[13] This can be important because the SO_2 program has been cited as a model for the regulation of other pollutants.[14] Furthermore, there is no need to exaggerate the savings of the SO_2 program. A proper accounting of the total costs of the program compared with a well-defined baseline indicates that savings have been substantial.

Economic Measure of Cost Savings

Measuring the cost savings attributable to allowance trading requires comparing total costs under trading with a counterfactual baseline description of what would have happened in the absence of the program. This approach to measuring the size of the gains from trade under the SO_2 trading program is explored in an econometric model by Carlson et al. (2000). Most previous studies, including those listed in Table 1, rely on engineering-based models of compliance options and their costs, but Carlson et al. use a simulation model based on marginal abatement cost functions derived from an econometrically estimated long-run total cost function

[12] On March 10, 1997, EPA Administrator Carol Browner argued, "During the 1990 debate on the acid rain program, industry initially projected the cost of an emission allowance to be $1500 per ton of sulfur dioxide...Today those allowances are selling for less than $100" ("New Initiatives in Environmental Protection," *The Commonwealth,* newsletter, March 31, 1997). In testimony before the House Commerce Subcommittee on Energy and Power on the economics of the Kyoto Protocol (March 1998), Janet Yellen, chair of the Council of Economic Advisers, noted that "emission permit prices, currently at approximately $100 per ton of SO_2 are well below earlier estimates...Trading programs may not always bring cost savings as large as those achieved by the SO_2 program."

[13] Smith, Platt and Ellerman, 1998.

[14] See "Economists' Cold Forecast; Assumptions: Expect their dire predictions about the impact of the global warming treaty on the United States. Ignore all of them," by Elaine Karmarck, *Baltimore Sun,* December 28, 1997.

for electricity generation for a sample of more than 800 generating units from 1985 to 1994.[15] From an economic perspective, this approach is superior because it takes into account substitution among inputs in response to changes in relative input prices.

Carlson et al. estimate that the potential cost savings attributable to formal emission trading, compared with the counterfactual of a uniform emission 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 emission rate standard. When compared with a forced scrubbing scenario, cost savings are estimated to be almost $1.6 billion ($1995) per year.

The Carlson et al. estimate is compared with several other estimates in Table 1. The most rigorous of these is Ellerman et al. (2000), which is based on an extensive survey of the industry with extrapolation to estimate long-run compliance costs.[16] Ellerman et al. 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. Earlier studies (Van Horn Consulting et al. 1993; GAO 1994) suggested that an efficient allowance market would result in cost savings of about twice as much as Carlson et al. in percentage terms. In all these studies, the command-and-control approach that is modeled is "enlightened": it is a performance standard (emission rate or emission tonnage standard) applied to each facility, calibrated to achieve the same level of total emissions.[17] This approach implicitly encompasses many of the beneficial incentives of the SO_2 trading program compared with a technology-forcing approach by providing individual facilities with flexibility in achieving the standard. Other command-and-control approaches that were seriously considered in the United States, such as forced scrubbing

[15] The cost function they estimate treats fuel type (high-sulfur and low-sulfur coal), labor, and generating capital as fully variable inputs. The econometric model consists of the cost function plus two share equations that specify the share of total costs attributed to capital and labor, and an equation for the firm's mean annual emission rate. The study uses a translog form for the cost function, adding dummy variables for each plant in the database to measure fixed effects that vary among the plants. Costs for units with scrubbers are taken directly from reported data. The model does not investigate whether early commitments to build scrubbers were economical, but several studies have suggested that several of these investments were not.

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

[17] In their command-and-control scenario, Carlson et al. (2000) apply a uniform emissions rate standard to all facilities. GAO (1994) and Van Horn Consulting et al. (1993) allow intrautility trading, but no trading between utilities. GAO (1994) also models a scenario that requires each facility to achieve its SO_2 allowance allocation without trading, and finds cost savings more than double when internal trading is allowed in the command-and-control baseline.

at larger facilities, could have cost substantially more. Forced scrubbing is also the approach embodied in the New Source Performance Standards for SO_2 from power plants.[18]

Table 1. Estimates of Long-Run (2010) Annual and Marginal Cost ($1995)

Study	*Annual cost (billions)*	*Marginal cost per ton SO_2*	*Average cost per ton SO_2*
Carlson et al. (2000)	$1.1	$291	$174
Ellerman et al. (2000)	1.4	350	137
Burtraw et al. (1998)	0.9		239
White (1997) [EPRI]		436	
ICF (1995) [EPA]	2.3	532	252
White et al. (1995) [EPRI]	1.4–2.9	543	286–334
GAO (1994)	2.2–3.3		230–374
Van Horn Consulting et al. (1993) [EPRI]	2.4–3.3	520	314–405
ICF (1990) [EPA]	2.3–5.9	579–760	348–499

A striking feature of the studies summarized in Table 1 is that, as a group, they have successively estimated a sequence of declining projections of annual and marginal costs of compliance. There are several contributing reasons for this trend. One is that the trading program ignited a search for ways to reduce emissions at less cost, as theory suggests is likely to occur with this type of regulation, and the fruitful results of this enterprise are measured by later studies.

Advantageous trends in fuel markets also contributed to a decline in emission rates, making it easier for utilities to attain the goals of the program and thereby reducing program costs (Ellerman and Montero 1998; Fieldston Company Inc. 1996; Burtraw 1996). Carlson et al. (2000) find that declining fuel prices lowered marginal control costs by about $200 per ton over

[18] 1978 Clean Air Act regulation of sulfur emissions from newly constructed fossil fuel–fired electricity generating facilities imposes a rate-based standard that requires a 90% reduction in a smokestack's SO_2 emissions, or 70% if the facility uses low-sulfur coal. Although nominally a performance standard, it effectively dictates technological choices and precludes compliance through the use of process changes or demand reduction. The only available technology to achieve such reductions is scrubbing, and the use of low-sulfur coal is not a permissible way to avoid the threshold for the strict standard.

the decade preceding 1990. The right-hand column in Table 1 reporting average cost per ton estimated by the various studies reflects this decline.[19]

A third reason why cost estimates are lower in later studies than in earlier ones is the role of unanticipated exogenous technical change that would have occurred in the absence of the program. Carlson et al. (2000) show that technical improvements, including improvements in overall generating efficiency, lowered the typical unit's marginal abatement cost function by almost \$50 per ton of SO_2 over the decade preceding 1995.

The Carlson et al. model can help sort out the contribution of these different factors to changing marginal abatement costs. Table 2 presents several estimates using this model, varying assumptions about fuel prices and technological change. The columns in the table represent the annual cost of a command-and-control approach (uniform emissions rate standard), the annual cost of efficient trading, its associated marginal abatement cost, and finally the estimated gains from trade that are available from efficient trading.

The first row in Table 2 reports numbers for a benchmark scenario that assumes relative fuel prices remain stable at 1995 levels and that technology, including the utilization rate of scrubbers, is characterized at 1995 levels.[20] This benchmark predicts long-run marginal abatement costs will be \$436 (\$1995). The second row presents an estimate 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.[21] From this vantage point, marginal abatement costs rise to \$560, or 28% greater. Notably, this is not far from the estimate offered by ICF (1990), calculated with comparable information and reported in the third row.

[19] Note that the different estimates of average control cost reflect different estimates of baseline emissions in the absence of the SO_2 emissions cap.

[20] The retirement rates for coal facilities and replacement with scrubbed coal technology are taken from projections by the Energy Information Administration (U.S. EIA 1996). The estimates assume that no additional retrofit scrubbers are constructed after Phase I. In fact, there have been eight scrubbers installed since the beginning of Phase II; however, the cost of these scrubbers is below that of the most efficient scrubbers installed in Phase I. Carlson et al. (2000) state that if scrubber prices fall below their estimate, then theirs should be interpreted as a high estimate of the costs of the program.

[21] Technological change here captures both exogenous efficiency improvements at the power plant and improvements induced by the program, but it does not capture improvements in scrubber technology and performance.

Table 2. Contribution of Price and Technological Change to Compliance Costs ($1995)

Scenario	*Command-and-control (millions)*	*Efficient trading (millions)*	*MAC*	*Potential gains from trade (millions)*
Benchmark estimate: (1995 prices and 1995 technology)	$2,230	$1,510	*$436*	$720
Benchmark with 1989 prices and 1989 technology	2,670	1,900	*560*	770
ICF (1990)	—	2,300–5,900	*579-760*	
Preferred estimate	1,820	1,040	*291*	780

The last row in Table 2 presents the Carlson et al. (2000) preferred estimate, reproduced for convenience from Table 1. Compared with the benchmark, this scenario adopts 1995 prices and 2010 technology. It assumes that utilization rates and performance of in-place scrubbers continue to improve. It assumes a slower retirement rate of coal-fired facilities, with half of retired facilities replaced by gas. Also it assumes that using continuous emission monitoring systems in place of the historical measure of emissions will raise emission estimates and necessitate a greater level of control.[22] Explicitly missing from consideration in all of these studies is the influence of other potential regulatory actions, such as further control on particulates or NO_x emissions or actions to meet global warming goals.

Economic Performance in the Early Years

There is ample evidence of cost savings in Phase I of the trading program. Ellerman et al. (2000) estimate savings of $350 million, about half of their measured cost of compliance. However, there is also evidence that the market did not perform perfectly.

Economic theory suggests that the marginal cost of compliance activities should be the same at all facilities (except as may be constrained by local ambient air quality restrictions). Compared with this measure, Carlson et al. (2000) find that, in the first two years of Phase I, actual compliance costs exceeded the least-cost solution by $280 million in 1995 and by $339 million in 1996 ($1995). To be fair, it must be noted that a command-and-control counterfactual also would be unlikely to achieve emission reductions in the least-cost manner. Nonetheless,

[22] In 1995 the continuous emissions monitors estimated 7% higher emissions than did the historic approach on average, although there was considerable variability among facilities.

there is evidence the allowance market did not achieve the least-cost solution during the first two years even though allowance prices and marginal abatement costs were approximately equal. Carlson et al. appear to confirm what many others suggest—that unfamiliarity with the new program led many to pursue a policy of "autarchy" (no trade) and self-sufficiency in compliance (Bohi 1994; Bohi and Burtraw 1997; Ellerman 2000; Hart 2000; Swift 2001).

Other studies have also found that utilities failed to take full advantage of the allowance market at the beginning of Phase I. Swinton (2002) analyzes the efficiency of sulfur dioxide control in Florida during Phase I. Using a panel of data for Florida power plants from 1990 through 1998, he estimates an output distance function and then uses this function to find the shadow prices of SO_2 emission reductions. He finds that power plants in Florida did not use the allowance market to its fullest potential: several plants are controlling emissions when purchasing allowances would be a more economic option.

Several analysts have pointed to state public utility regulation and other state laws as an influence that has tended to undermine the efficiency of the SO_2 market, and if that is the case, the effect can be significant.[23] Prior to implementation and during the early years of the program, there was a great deal of uncertainty in many states about how regulators were going to treat allowance transactions in setting regulated rates that damped utilities' enthusiasm for using the allowance market (Burtraw 1996; Bohi 1994). Rose (1997) suggests that public utility commission (PUC) activities have discouraged the use of the market in favor of strategies such as fuel switching. Rose et al. (1993) and Lile and Burtraw (1998) document PUC actions to promote use of local high-sulfur coal.

Empirical studies have used econometric techniques to examine the extent to which PUC regulation has affected the performance of the SO_2 market. Arimura (2002) suggests that such an analysis should focus on compliance decisions at the generating unit level, seeking to identify whether units with relatively low marginal abatement costs are reducing emissions while those with higher costs are buying permits. Using data for the Phase I time period, he estimates a probit model of the choice between fuel switching and allowance purchases coupled with continued use of high-sulfur coal as compliance strategies.[24] He finds that, holding abatement costs and other characteristics fixed, units facing PUC regulations are more likely to rely on fuel

[23] Winebrake et al. 1995; Fullerton et al. 1997.

[24] This analysis excludes those units that installed scrubbers for compliance.

switching than the allowance market for compliance.[25] He also finds that in states with high-sulfur coal, where efforts were made to protect local coal producers, there was greater use of allowance purchases than fuel switching or blending for compliance.

Arimura then uses the model to simulate what compliance strategies would be adopted in the absence of PUC regulation and without protection of high-sulfur coal markets. He finds that PUC regulation has a stronger effect on compliance behavior than did the protection policy. He also finds that the allowance price would have been higher in the absence of PUC regulation. This finding helps explain why allowance prices during Phase I were lower than anticipated.

Sotkiewicz (2002) used utility data for 1996 and exercised a simulation production cost model to evaluate firm performance. He also finds that utility compliance costs due to state-level PUC regulation were above least cost, ranging from 4.5% to 139% above least cost. PUC regulations governing cost recovery for investment in scrubbers led to the majority of cost increases.

In sum, the question about performance in the early years of the program is one of perspective. Emission trading is a new institution that might pass through a period of transition to a mature and efficient market. The issue of performance in the early years may be relevant to the design of trading programs in the future. However, all the literature appears uniformly to express the expectation for, or to provide evidence of, improved performance in the allowance market over time. The volume of trading doubled each year over the first three years of the program, suggesting a process of learning on the part of firms.[26] Also, increasing competition in the electricity sector puts pressure on firms to reduce costs and take better advantage of trading.

Cost Savings over Time

Analysts who offer a direct comparison of current short-run allowance prices with estimates of long-run marginal costs of emission reductions have tended to exaggerate the cost savings from allowance trading. Economic theory suggests that short-run and long-run measures

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[25] In contrast, Bailey (1996) finds that PUC decisions did *not* impede use of the allowance market. She investigates the effect of PUC rulings clarifying the regulatory stance on allowance trading. Using state-level data on market participation, she estimates a probit model to see whether PUC guidelines and rulings had an effect on utility participation in the allowance market within a state. The study found that PUC rulings had a positive correlation with trading activities, but that the causal relationship may have been the reverse—that is, that the desire to participate in the market often prompted utilities to request regulatory rulings to reduce uncertainty.

[26] Kruger and Dean, 1997.

should indeed be related, but they are not directly comparable. The two measures should be related by the opportunity cost of holding emission allowances that is, the interest rate.

In the short term, firms should be expected to reduce emissions to the point where the marginal cost of doing so equals the discounted present value of marginal costs in the long run. Over time, one would expect the bank to be drawn down in a smooth manner such that the allowance price in one year is related to that in future years by the rate of interest (Rubin 1996; Cronshaw and Kruse 1996).

Using this relationship from economic theory provides one way to check on the performance of the market and the likely accuracy of estimated costs. Applying a discount rate of 8%, the present discounted value of long-run marginal cost estimates of $291 in 2010 (Carlson et al. 2000) is about $157 in 2002. Allowance prices hovered between $130 and $170 for most of 2002, suggesting that the Carlson et al. model is roughly consistent with current experience, and that intertemporal arbitrage is working to an important degree.

Ellerman and Montero (2002) also argue that banking has been an efficient means of compliance. Ellerman et al. (2000) estimate that savings from banking total $1,339 million over 13 years in their central case, with the Phase II bank drawn down over 8 years. This is 7% of total savings over the 13-year period, and just slightly less than the savings from spatial trading of allowances during Phase I (9%) and substantially less than savings from spatial trading in Phase II (84%). However, the authors emphasize that although banking is a relatively minor source of total savings, it is a valuable feature of a successful trading program because it provides firms with the ability to "avoid the much larger losses associated with meeting fixed targets in an uncertain world (Ellerman et al. 2000, p. 285).

Consequently, despite evidence of differences in marginal costs among firms suggesting some lost opportunity to reduce costs in the short run, there appears to be efficient behavior over time in the aggregate. The trend in allowance prices over time suggests intertemporal planning that is consistent with economic theory.

General Equilibrium Costs

A full accounting of costs must take account of the interaction of the program with the full economy. An important literature has studied the interaction of regulatory programs with the preexisting tax system, such as the tax on labor income. A tax imposes a 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). Any additional regulation that raises product prices potentially imposes a hidden cost on the economy by further lowering the real wage of workers. This can be viewed as a "virtual tax" magnifying the significance of previous taxes, with losses in productivity as a consequence.[27]

Economic instruments are likely to impose a greater cost through the tax interaction effect than prescriptive approaches because they have a greater effect on product prices, and this tends to offset some of the reduction in compliance costs. The reason economic instruments have a greater effect on product prices is that when economic instruments are used, firms must not only comply with environmental standards but also internalize the opportunity cost of the remaining emissions. In the SO_2 program, this occurs through the cost of emission allowances.

Goulder et al. (1997) investigated the magnitude of the tax-interaction effect in the context of the SO_2 program using both analytical and numerical general equilibrium models. They find that this effect will cost the economy about \$1.06 billion per year (\$1995) in Phase II of the program, adding an additional 70% to their estimated compliance costs for the program. That estimate would pertain in the long run if the entire electricity sector sets prices in the market rather than bases them on cost of service. If price is based on cost of service, then the regulatory burden is much lower because allowances under Title IV were distributed at zero original cost. The hidden cost of the tax-interaction effect would be reduced substantially, but not entirely, if the government auctioned the permits and used the revenues from the auction to reduce preexisting distortionary taxes. However, under grandfathering, the revenue is not available for this purpose.

If the entire industry is deregulated, the cost of the tax interaction effect could be substantial. Table 3 illustrates the relative potential cost savings from allowance trading and the hidden costs of the use of grandfathered emission allowances, compared with the costs under a command-and-control approach. The values in this table are expressed in percentage terms, normalized around the values in the first cell. This value in the first cell in the first row represents the least-cost estimate of compliance in 2010, or partial equilibrium cost, estimated by Carlson et al. (2000) and reported above. The second cell in the first row represents the ratio of compliance (partial equilibrium) costs under the command-and-control scenario modeled in that study to costs under the least-cost approach, about 135% of the least-cost outcome.

[27] 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 an general equilibrium framework.

Table 3. General Equilibrium Cost of SO_2 Allowance Trading as Percentage of Partial Equilibrium Least-Cost Compliance

Percentage values normalized around first cell	*Least-cost compliance (%)*	*Command-and-control performance standard (%)*
Partial equilibrium measure	100	135
General equilibrium measure		
with revenue	129	*n/a*
without revenue	171 (Title IV)	178

The remaining rows reflect estimates of cost in a general equilibrium context. The first column summarizes the Goulder et al. (1997) finding that the general equilibrium costs of a market-based policy (emission tax or auctioned permit system) are about 129% of the partial equilibrium measure of costs in the least-cost solution. The bottom row indicates that the cost of a permit system that fails to raise revenues is about 171% of the least-cost partial equilibrium estimate.

The last cell in the bottom row of the table yields an estimate of the relative cost of command-and-control policies in a general equilibrium setting. We find that the type of policies modeled in the context of the SO_2 program, a uniform emissions standard applied to all sources, would result in general equilibrium costs that were 178% of those measured in the least-cost solution in a partial equilibrium framework.[28] In other words, the general equilibrium cost of the tradable permit program (171) is only slightly less than the general equilibrium cost of a command-and-control program (178). The example suggests that the failure to raise revenue and to use that revenue to offset distorting taxes squanders much of the cost savings in compliance costs that can be achieved by a flexible tradable permit system. As the electricity industry moves away from cost-of-service (regulated) prices to market-based (deregulated) prices for electricity, this failure will have greater relevance in the context of the SO_2 program.

[28] The number 1.78 (178%) is the product of 1.29 times 1.35 times 1.02. The number 1.29 is the ratio of general equilibrium to partial equilibrium cost from Goulder et al. (1997) for a policy that raises revenue, such as an emissions tax. The number 1.35 is the ratio of command-and-control to efficient least-cost from Carlson et al. (2000). The number 1.02 is the ratio of general equilibrium costs for a performance standard relative to an emissions tax identified in Goulder et al. (1997).

Compliance Methods and Technological Change

Despite regulatory issues and less than fully efficient performance by the allowance market in the first years of Phase I, there is ample evidence that the flexibility associated with allowance trading has contributed to dramatic cost savings compared with traditional regulation and to efficiency improvements that have reduced the cost of controlling SO_2 emissions. Burtraw (1996) argues that Title IV created competition between intermediate industries. What were previously independent factor markets supplying services to utilities (coal mining, rail transport, and scrubber manufacturing) were thrown into a competition with each other by the program's flexible implementation in a race to supply the electricity generating industry with low-cost compliance strategies.[29] This unleashed competitive pressure to find ways to reduce costs in all these markets. The result has been a decline in the delivered cost of low-sulfur fuel and improvements in the performance of scrubbing.

The primary technological reason for the decline in costs has been a dramatic reduction in the delivered cost of low-sulfur coal. A review of changes in the receipts for coal distinguished by sulfur content reveals that between 1990 and 1994, sales of low-sulfur coal (defined as less than 0.6 pounds of sulfur per million Btu) increased by 28% while price fell by 9%. Meanwhile, sales of high-sulfur coal (defined as greater than 1.67 pounds of sulfur per million Btu) fell by 18%, though prices fell by only 6%.[30]

Two trends explain the accelerated decline in the price of low-sulfur coal. The most important has been the reduction in cost of rail transportation of low-sulfur western coal, driven by investment and innovation in the rail industry. Rail transportation constitutes about 50% of the total cost for low-sulfur coal from the West delivered to the East, as western coal is considerably cheaper to mine than eastern coal. Coal transportation prices in the East are 20–26 mills (1 mill = 1/10 cent) per ton-mile. However, competition in rail for western coal caused prices in Phase I to drop to an average of 10–14 mills per ton-mile.

A second explanation for declining coal prices is that the capital and other costs expected for using low-sulfur coal have failed to materialize because of the flexibility offered by Title IV.[31] With traditional emission rate limits, or even an emission cap at individual facilities, facilities would be faced with either installing scrubbers or switching entirely to low-sulfur coal,

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[29] Heller and Kaplan, 1996.

[30] U.S. EIA (1991, p. 68; 1995a, p. 91; 1995b), Resources Data International (1995).

[31] Burtraw, 2000.

with associated capital investments in handling facilities. However, another compliance strategy that has taken hold in the wake of Title IV is the blending of subbituminous low-sulfur and bituminous high-sulfur coal. Prior to Title IV, it was thought that blending different fuels would not be feasible,[32] but experimentation in response to the allowance market has shown that the detrimental effects of blending low-sulfur coal with other coals are smaller than originally thought.

Scrubber prices per kilowatt of installed capacity remained fairly constant through Phase I (Keohane 2002).[33] This may be because induced innovation for scrubbing technology appears to have peaked before Title IV as a result of NSPS requirements to install scrubbers, and this appears to have lowered the cost of operating scrubbers before 1990 (Popp 2001).

However, patents granted during the 1990s, when the SO_2 trading program provided incentives to improve performance, appear to have improved the removal efficiency and reliability of scrubbers (Popp 2001). Furthermore, under the SO_2 program, less capacity was needed to achieve roughly equivalent reductions. Previous to CAAA, scrubber systems usually included a spare module to maintain low emission rates when any one module was inoperative. One estimate indicates that a spare module would increase capital costs by one-third (U.S. EIA 1994). An important innovation is the reduced need for spare absorber modules, as allowances can be used for compliance during maintenance periods or unplanned outages. In addition, the increased efficiency and reliability of scrubbers have reduced maintenance costs and increased utilization rates, and also the need for spare modules.

Keohane (2000) and Taylor (2001) both find that abatement costs per ton of removal have fallen substantially, especially in retrofit scrubbers installed for compliance in the SO_2 program. In addition, there is significantly increased utilization of scrubbed units (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 more tons reduced. Before the SO_2 program, scrubbers did not exhibit reliability rates sufficient to achieve the current level of utilization.

Nonetheless, about half as many scrubbers were installed under Phase I as were originally anticipated. This occurred even though the allowance program itself encouraged scrubbing by allocating 3.5 million "bonus" allowances to firms that installed scrubbers as the means of

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[32] Torrens, Cichanowicz and Platt, 1992.

[33] In contrast, Taylor (2001) finds that capital costs have declined significantly over time.

compliance, for the explicit purpose of protecting jobs in regions with high-sulfur coal. As this survey shows, there are several ways in which scrubbing faced competition.

Voluntary Participation

Another source of additional allowances under the cap comes from the inclusion of units that voluntarily subscribed to the program under the industrial opt-in provisions or the utility substitution or compensation provisions. These provisions were available to facilities that were not covered by the first phase of the program, and they had an incentive to participate if they could reduce emissions at a marginal cost that was less than the allowance price. The units received allowances equal to a forecast of their emissions for industrial facilities if they did not participate, or allowances similar to allocations for other Phase I units for utilities, and participants could sell unused allowances if they reduced their emissions. Most of the participation was by utilities that had already installed monitoring equipment.

Montero (1999) finds that the voluntary provisions led to significant adverse selection. Changes in coal prices and the utilization of power plants caused the true counterfactual baseline for many units to differ from the formulas that were applied, providing an opportunity for some units to harvest allowances for emission reductions that would have occurred anyway. The rules encouraged this adverse selection by allowing units to wait until the end of the year before declaring whether to participate, and by allowing units to determine their participation on a year-by-year basis. Although the voluntary provisions amount to only a small part of the overall program, they illustrate a flaw in the program design that could be important in other situations.

Administration and Compliance

Implementation of the SO_2 trading program has been characterized by low administrative costs and a high level of compliance. One reason is that industry shared an interest in the implementation of the program. If EPA failed to implement regulations in a timely manner, then emission limitations stated in the law would apply to every source, absent the opportunity for trading (McLean 1997). Also, there is little area for dispute in a cap-and-trade program, since the law establishes the standard and the basic allocations. Few lawsuits were filed to slow the implementation of trading, and those concerned rules for substitution units and other allocation issues (Swift 2001).

The program enjoyed 100% compliance in all years of Phase I, and since then, only an unimportant compliance failure by owners of two units, who were short a total of 11 allowances to cover their emissions for 2001, have marred the program. That failure was an administrative mistake that could occur only because compliance activities had become routine. It did not result in excess emissions. This compares with the 80% compliance typical under other federal air programs (Swift 2001).

Two technical features contribute to simple administration and successful compliance. One is the continuous emissions monitoring system (CEMS) that contributes to the confidence that emission reductions are being achieved.[34] The other is the high, and certain, penalty that is levied for noncompliance.[35]

6. Conclusions

The SO_2 program has become an international model for a cap-and-trade program, and there are several features that set its performance apart from traditional prescriptive approaches to regulation. Although utility regulation and other factors inhibited utilities from taking full advantage of the allowance market, particularly in the early years of the program, there is ample evidence that allowance trading has achieved cost savings. This is especially true if one evaluates the program relative to realistic possibilities for command-and-control approaches. Even compared with "enlightened" command-and-control, however, trading has allowed utilities to take advantage of advantageous trends in fuel markets, especially the expanded availability of low-sulfur coal, in ways that more rigid technology-forcing approaches to regulation would have precluded. The program has also resulted in innovation through changes in organizational technology, in the organization of markets, and through experimentation at individual boilers, much of which arguably would not have occurred under a more prescriptive approach to regulation. In addition, the program is viewed as administratively transparent. Penalties are certain and compliance has been virtually perfect. The mechanism of allowance trading for SO_2,

[34] Continuous monitoring may not be necessary for a trading program to work. Protocols could be developed to deal with concerns about measuring emissions or emissions reductions at sources that are difficult to monitor. Such protocols have been proposed for managing trades between point and nonpoint sources of water pollution. Ellerman et al. (2000) estimate the cost of a continuous monitoring system to be about $125,000 per unit, or 7% of total direct compliance cost.

[35] In addition to surrendering allowances for a subsequent year, units with insufficient allowances in their accounts must pay an automatic penalty of $2,000 per ton ($1990) adjusted for inflation.

if not always the levels of the cap, have become popular with most in industry and in environmental advocacy.

In addition to being cost-effective, the SO_2 program has resulted in greater-than-expected benefits, with aggregate benefits estimated to be an order of magnitude greater than aggregate costs once the program is fully implemented. Moreover, despite its lack of geographic resolution in an effort to protect key affected areas, trading under the program has not affected, and may have benefited, sensitive ecosystems and human health.

One limitation of the trading program is its inability to adapt to new scientific or economic information. As new information has become available about the relative benefits and costs of SO_2 reductions, there has been no ability to change the cap short of an act of Congress.[36] The emission cap leaves regulators with their "feet stuck in cement"—unable to adjust to new information (Zuckerman and Weiner 1998; Swift 2001). A more prescriptive approach, such as the NO_x provisions of Title IV, shares this attribute.

An alternative to a firm cap would be a cap that adjusted in response to new information. Others have suggested similar trigger mechanisms on emission caps to provide economic relief if costs are greater than expected (Pizer 2002), but such an approach might better be coupled with a mechanism that provides further environmental improvement when costs are less than expected. A safety valve that relaxes the cap when allowance prices hit a specified level, and lowers the cap when allowance prices are below a floor, would act like a tax system in this regard by incorporating new information about costs.

The Future

The perceived success of the SO_2 program in terms of reducing compliance costs, coupled with new information about the benefits of reducing air pollution, has contributed to a new wave of legislative proposals aimed at further reducing SO_2 emissions from power plants.[37] It reflects a remarkable consensus in the policy community that all the proposals would expand the use of a cap-and-trade approach to achieve these emission reductions, and the proposals

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[36] A related concern is that tradable permits may instill a property right that would be difficult to change. This was forestalled in the design of Title IV by explicitly stating that allowances did not constitute a property right.

[37] The Jeffords (I-VT) bill (S.556) caps annual allocations of SO_2 emission allowances at 25% of the 8.9 million tons allocated annually under Title IV (2.25 million tons). The Bush administration's Clear Skies proposal, sponsored by Sen. Smith (R-NH) as S.2815, caps annual emissions of SO_2 at 4.5 million tons in 2010 and 3.0 million tons in 2018. The Carper (D-DE) bill (S.3135) caps annual emissions of SO_2 at 4.5 million tons in 2008, phasing down to 2.25 million tons in 2015.

extend this approach to the regulation of NO_x at a national level as well. Most would also apply cap-and-trade to achieve reductions in mercury and carbon dioxide (CO_2) as well.[38] Trading of mercury allowances is controversial because mercury is a hazardous air pollutant, and inclusion of CO_2 is controversial because mandatory CO_2 reductions are absent from the Bush administration's proposal.

The potential long-run success of efforts in the United States to control SO_2 emissions in an economically efficient manner is illustrated in Figure 4. This figure portrays expected emissions from the electricity sector in the year 2020 under various scenarios. The first is a business-as-usual scenario (BAU), reflecting a forecast of emission levels that may have obtained in the absence of Title IV and other aspects of the Clean Air Act, such as eventual enforcement of new particulate standards that are likely to require reductions in SO_2 emissions. Also reported is the forecast of about 9 million tons per year of emissions, corresponding for an average year to the annual allocation of SO_2 emission allocations after the bank achieves an equilibrium. The next three bars in the figure represent the three multipollutant proposals. Note that the Clear Skies Initiative (CSI) will have annual emissions slightly above annual distribution of allowances because the bank is not expected to be in equilibrium yet under that policy. Finally, at the right is an estimate of the efficient level for SO_2 emissions under a cost-effective regulatory policy, such as emission fees or a cap-and-trade program coupled with an allowance auction. This estimate is the result of an integrated assessment linking the Tracking and Analysis Framework model of atmospheric transport and health benefits (excluding ozone) from reductions in SO_2 emissions with another model of electricity markets.[39] The bar indicates the 90% confidence interval around the mortality, morbidity, and valuation estimates in the benefits model (Banzhaf et al. 2002).

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38 For a comparison of the bills, see http://www.rff.org/multipollutants.

39 TAF was developed to support the National Acid Precipitation Assessment Program (NAPAP). The entire model and documentation (Bloyd et al., 1996) is available at www.lumina.com\taflist.

Figure 4. SO_2 Electricity Sector Emissions in 2020

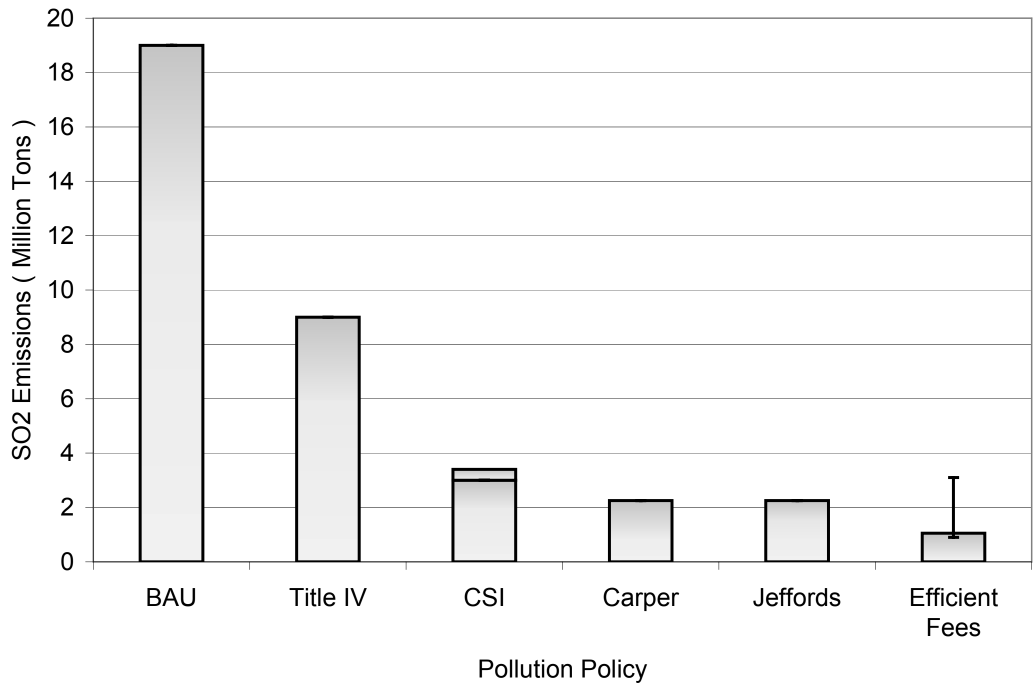

Figure 4 illustrates that if any of the multipollutant proposals on the table were to pass, emissions would fall within the range identified as efficient by benefit-cost analysis. Furthermore, under all these proposals, emission reductions would be achieved using a cap-and-trade approach that promises to achieve the reductions in a cost-effective manner. This is important because the cost of achieving emission reductions feeds back into the level of reductions that can be justified on the basis of benefit-cost analysis. If the program were more expensive, as would be expected under a traditional regulatory program, or possibly from a cap-and-trade program that was not well designed, then benefit-cost analysis would suggest a higher level of emissions as the efficient target.

The SO_2 program has accomplished a remarkable reduction in emissions. But equally remarkable, from a policy perspective, is that the program has fundamentally changed the nature of environmental policy. The program was viewed by many in 1990 as ideologically motivated, at best, and a fraud at worst.[40] From across the political spectrum, today the cap-and-trade approach is the centerpiece of proposals for U.S. environmental policies.

[40] Seligman, 1994.

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