Environmental Effects of SO₂ Trading and Banking

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The widely acknowledged innovation of Title IV of the 1990 Clean Air Act Amendments is sulfur dioxide allowance trading, which is designed to encourage the electricity industry to minimize the cost of reducing emissions. Few studies have examined the environmental effects of trading, and none have explored the effects of banking. We used an integrated assessment computer model, the Tracking and Analysis Framework, to evaluate changes in emissions of SO₂, atmospheric concentrations of sulfates and deposition of sulfur, and public health benefits from reduced exposure to SO₂ and particulate matter. We assessed geographic and temporal changes at the state level that result from trading and banking and compared them with estimated cost savings. Our findings are not consistent with the fears of the program’s critics. In the East and Northeast including New York State, an area of particular concern, we found that health benefits increase and sulfur deposition decrease slightly as a result of trading. Nationally, trading results in health-related benefits in addition to significant cost savings. Banking changes the timing of emissions, but the geographic consequence of banking is varied.

Introduction

The widely acknowledged innovation of Title IV of the 1990 Clean Air Act Amendments (CAAAs) is sulfur dioxide (SO₂) allowance trading, which is designed to encourage the electricity industry to minimize the cost of reducing emissions. Title IV sets an annual cap on average aggregate SO₂ emissions by electricity generators. The cap ultimately will fall to about one-half of emissions in 1980. Firms surrender one emission allowance for each ton of sulfur dioxide emitted. Allowances are allocated to individual facilities roughly in proportion to fuel consumption during the 1985–1987 period. Firms may transfer allowances among facilities or to other firms. In addition, the emission cap accommodates an allowance bank, enabling firms to accumulate surplus allowances for use in subsequent years.

The environmental consequences of trading have been the subject of considerable speculation and acrimony, especially in the Northeast, which is widely thought to be the recipient of pollution emitted by power plants in the Midwest. In 1993, the Attorney General of New York sued the U.S. EPA to restrict allowance sales to guarantee protection of the state’s resources. Subsequently, legislation passed the New York State Assembly to constrain allowance trades between in-state utilities and other entities. A similar bill passed the State Senate in 1999. In April 1998, the State announced an agreement with Long Island Lighting Company (LILCO) to preclude sale of emission allowances from LILCO to other utilities for use at plants in 15 states thought to cause acid rain in New York. Senator D’Amato likened the long-range transport aspect of the acid rain problem to “airborne terrorism” when he joined Senator Moynihan in 1998 in proposing legislation that would impose dramatic further reductions in emissions. [Testimony regarding S.1097 before the Clean Air Subcommittee, Environment and Public Works Committee, October 6, 1998.]

Similarly, the environmental consequences of banking are ambiguous. To build up a bank, emissions are reduced in the near-term, leading to greater environmental benefits in the early years of the program. “Overcompliance” to date has been trumpeted by the Environmental Protection Agency as a measure of success. However, the depletion of the aggregate allowance bank that is expected to begin in 2000 will enable annual emissions to exceed annual allowance allocations for several years and is likely to ignite unfavorable opinions from environmental advocates.

The SO₂ program now serves as an international model for reducing the costs of pollution reduction. In September 1998, the EPA announced another substantial trading program for NOₓ emissions that will affect electric utilities in 22 eastern states and which is explicitly based on the “success” of the SO₂ program. The proposed NOₓ program differs from the SO₂ program because states would opt in or out of a regional trading program. Also, banking of emission allowances would be restricted due to concern about NOₓ as a precursor to ozone, which is an episodic pollution problem. Despite the acrimony about its environmental consequences and the enthusiasm for potential cost savings, there exists little environmental analysis of SO₂ trading and banking.

We used an integrated assessment computer model to evaluate changes in emissions of SO₂, atmospheric concentrations of sulfates and deposition of sulfur, and public health benefits from reduced exposure to SO₂ and particulate matter. We assessed geographic and temporal changes at the state level that result from trading and banking and compared them with estimated cost savings. In brief, we find a sizable geographic and temporal shift in emissions, in some states over 20% of emissions, due to trading and banking. However, the geographic consequences are not consistent with the fears of the program’s critics. By holding aggregate emissions constant at the expected levels obtained under the program, pollutant concentrations decrease and health benefits actually increase in the East and Northeast due to trading. The expected result is health-related benefits nationally of nearly $125 million in 2005 as compared to a scenario with equal aggregate emissions that did not allow trading. Deposition of sulfur in the eastern regions also decreases by a slight amount as a result of trading even in New York State. Meanwhile, cost savings from trading totals $531 million, about 37% of compliance cost in 2005.

Banking has a predictable effect on the timing of emissions and the benefits of emission reductions, but the geographic pattern of emission changes is not simple. In 1995, emission reductions due to banking led to decreased concentrations and deposition. Some states reduce emissions in 2005, but there is an overall increase, uniformly leading to increased concentrations and deposition.

Background

Economists urge the use of market-based approaches such as emission permit trading because they are expected to...
control pollution at a lower cost than traditional command-and-control approaches. Rather than forcing firms to emit \( \text{SO}_2 \) at a uniform rate or to install specific control technology, the opportunity for trading should provide an incentive for low-cost firms to assume a relatively greater share of emission reductions.

Banking is thought to offer similar opportunities for cost savings by offering firms flexibility in timing their compliance activities. Title IV is implemented in two phases. The first phase began in 1995 and affected the largest coal-fired power plants. The second phase will begin in 2000 and will tighten average emission rates and affect several hundred additional facilities. A firm may overcomply at one facility (a frequent occurrence during the first phase of the program) to create an allowance surplus that can be sold or used to delay further investments at other facilities.

Ultimately, total emissions will be cut about in half; however, the full effect of the emission reductions will not be felt until about 2010, when the allowance bank built up in Phase I is depleted. To date, the program has achieved full compliance, and a substantial bank is accumulating, primarily for use in Phase II. [A historic summary of emissions and allowance trading activity is provided in Appendix A in the Supporting Information. Complete data on allowance allocations, holdings, and emissions can be obtained at http://www.epa.gov/acidrain/trading.html.]

The \( \text{SO}_2 \) program places no controls on the regional pattern of trading, although environmental damages vary with the location of emissions. An early version of the legislation would have divided the nation into two trading regions in order to preclude broad geographic shifts in the pattern of emissions. The decision not to divide the nation in the final legislation was intended to expand the opportunity for cost savings by including more potential traders within a single market, thereby improving market liquidity, and by incorporating more heterogeneity in costs in the market.

Few studies have examined the issue of trading, and none have explored the geographic impact of banking. The Environmental Protection Agency (1) finds that most allowances surrendered for compliance in 1995 and 1996 were used in the same state as they were allocated, leading the authors to conclude that little geographic shifting of emissions due to trading has occurred. [A referee notes that the evidence is not definitive. A firm may surrender allowances that are part of its endowment and conserve allowances obtained from out of state.] However, several authors suggest that the amount of allowance trades to date has been less than necessary to capture fully the potential gains from trading (2-4). Two papers have compared actual trading to the costs and benefits of trading identified in optimization models and found that potential cost savings were not fully realized in 1995 and 1996 (5, 6).

We solved an optimization model to identify the pattern of trades that would minimize costs; hence, our results may differ from observed patterns if regulated electric utilities do not minimize costs. However, our model captures the economic logic that motivates the trading provisions of the program. Over time, one can expect unrelated regulatory changes already underway in the industry to increase incentives to reduce costs, and this should lead to trading activity in accord with our model. Indeed, Kruger and Dean (7) find the volume of trading has virtually doubled every year since 1994, and this trend continues to the present.

The Tracking and Analysis Framework

The Tracking and Analysis Framework (TAF) is a nonproprietary and peer-reviewed model constructed with the Analytica modeling software (8). [Appendix B in the Supporting Information provides additional detail. The model is available at http://www.lumina.com/taf/index.html.] TAF integrates models of electric utility emissions and costs, pollutant transport and deposition (including formation of secondary particulates but excluding ozone), visibility effects, effects on recreational transport through changes in soil and aquatic chemistry, human health effects, and valuation of benefits. Each module of TAF was constructed and refined by a group of experts in that field and draws primarily on peer-reviewed literature to construct the integrated model. TAF itself was subject to an extensive peer review in December 1995, which concluded that “TAF represents a major advancement in our ability to perform integrated assessments” and that the model was ready for use (9). Monte Carlo simulation is used to represent uncertainty and variation in climatological, health, aquatic, and visibility effects as well as valuation (10-13). Burtraw et al. (13) utilized TAF to construct a cost–benefit analysis of Title IV. They found that benefits substantially outweigh the costs of the program, in part because of the reduction in costs associated with allowance trading. The majority of benefits result from reduced risk of premature mortality, especially through reduced exposure to sulfates. Significant benefits are also estimated for improvements in health morbidity, recreational visibility, and residential visibility, each of which measures approximately equal to costs.

We focus on the human health mortality and morbidity effects of Title IV in estimating monetary benefits resulting from changes in air pollution concentrations. Impacts are expressed as the number of days of acute morbidity effects of various types, the number of chronic disease cases, and the number of statistical lives lost to premature death (8). The model calculates benefits as estimates of the willingness-to-pay to avoid these health effects. We also evaluate changes in atmospheric deposition of sulfur, which proxies for other environmental effects of interest.

The estimates of cost use an algorithm for determining compliance activities developed by Argonne National Laboratory. Compliance options for \( \text{SO}_2 \) reductions include scrubbing, fuel switching (including plant modifications), and fuel blending. Retirement is determined exogenously. Emission allowance trading is modeled implicitly by allocating compliance in a cost-effective way.

The Effects of Trading

To explore the regional effects of trading, we compare two scenarios:

Baseline Scenario. Expected compliance with Title IV with trading and banking. [A constraint on the investment algorithm is that facilities that chose to scrub in Phase I scrub in the baseline scenario. The prices of various compliance options that were obtained over the nineties render many of the decisions to install retrofit scrubbers uneconomic ex post (5) and would not be chosen given the prices of compliance options reflected in the model.]

No Trading Scenario. Aggregate emissions approximate those in the baseline, but compliance is achieved without trading. [The baseline and no trading scenario aggregate emissions are within 1% in 2005. The baseline has slightly more allowances, placing a downward bias on the benefits from trading. An alternative would be to constrain individual facilities to emit at less than or equal to their allowance allocation, thus taking away the opportunity to trade. Since compliance technologies usually do not provide a continuous range of emission reductions, many facilities would emit less than their allowance allocation, leading to lower aggregate emissions than in the baseline (14).]

In both scenarios, an intertemporal investment algorithm is solved to minimize net present value of compliance. In the no trading scenario, 15 facilities choose to scrub in addition to those that scrub in the baseline. At these facilities,
scrubbing is less costly than fuel switching or blending given their location and the transportation costs associated with alternative fuel choices. In the baseline, these units were purchasers of allowances, but this option is not available in the no trading scenario.

Emission and Deposition Changes from Trading. Figure 1 presents the percent changes in SO\(_2\) emissions by state from electricity generation attributable to trading for 2005. Although emissions increase in the Ohio Valley, they do not do so in all states. The effect of trading on most states outside the Ohio Valley is to reduce emissions. (The state-by-state results for this and other evaluations are reported in Appendix C in the Supporting Information. Illinois, Iowa, Kentucky, Tennessee, Texas, and Wisconsin are expected to buy more permits in 2005 than they sell. Logit analysis indicates that the distance to the low sulfur coal supply and the age of the unit are significantly correlated with this status. Generating units from these states that had not already decided to switch fuel or scrub by 1993 are more likely to purchase permits because of relatively high fuel transportation costs and capital recovery factors.)

We find that Midwestern states experience increases in deposition (the annual sum of wet and dry sulfur deposition) in 2005. The deposition change is more uniform within the region than the change in emissions because of atmospheric dispersion and transport.

We obtain the opposite results in the northeastern, eastern, and southeastern states, where decreases in deposition are predicted to result from trading. Figure 2 displays this information as the percent change in deposition by state attributable to trading.

Two previous studies have addressed this issue. The EPA (ref 15, p 78) compared sulfur deposition for several scenarios, including one that simulated trading, and projected that most areas would experience a slight increase in deposition attributable to trading in 2010. The expected change is less than 10%, usually much less, especially in the Adirondack region of New York. Our results are consistent with respect to the order of magnitude; all the states in our model experience changes in deposition of less than 8% attributable to trading. However, we project that the entire eastern region (including New York State) will experience a decrease in

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**FIGURE 1.** Percent change in Title IV baseline utility emissions attributable to trading for 2005.

**FIGURE 2.** Percent change in Title IV baseline sulfur deposition attributable to trading for 2005.
deposition. This holds despite the bias of slightly greater aggregate emissions in the baseline than in the no trading scenario.

NAPAP (16) offered hypothetical illustrations of changes in emissions and deposition that could result from trading. One illustration compared an emission rate standard with a policy that would impose reductions at 120 facilities with the highest emission rates, which was intended to proxy for trading (ref 16, p 447). This proxy led to no change or a slight reduction in deposition in most of the East including New York. Another example compared equal percent reductions at all sources with a proxy for trading, characterized as equal emission rates within states (but variation among states) (ref 16, p 256). The example found slightly higher to moderately lower levels of deposition among the states in the proxy for trading, roughly consistent with our results in order of magnitude but lacking a connection to an underlying economic model.

Health Benefits from Trading. In the aggregate, net health-related benefits of trading total $124 million (1995 dollars, no discounting) in 2005. The regional implications for the distribution of benefits are displayed in Figure 3. Again, the fear that citizens in New England and the eastern seaboard might suffer health effects as a consequence of emission trading seems unlikely. Increased emissions in the Ohio Valley imply decreased emissions in other states that have an equal to or greater impact on more populated areas in the east.

Effects of Banking

Banking is expected to accumulate a surplus of nearly 11 million allowances by 2000, which will be drawn down over the next decade. To examine the effects of banking we compare two scenarios:

Baseline Scenario. Expected compliance with Title IV with trading and banking.

No Banking Scenario. Emissions set to be less than or equal to the allowance allocation in the baseline in each period. (The 1990 statute awarded 3.5 million “bonus allowances” in Phase I to facilities that scrub. These allowances would have little value without the opportunity to bank them. In the no banking scenario, they are reallocated to the years when they are used for compliance in the baseline scenario.)

The intertemporal investment algorithm results in a shift in emissions over time. We report two snapshots, for the years 1995 and 2005, when the bank is estimated at 3.6 and 6.9 million t, respectively. Note that even after 2010, when depletion of the allowance bank is expected and annual emissions in these scenarios are equal, the geographic pattern of emissions will differ due to different investments in compliance capital that will survive beyond 2010.

In the baseline scenario, the installation of 21 retrofit scrubbers during Phase I reduces emissions at these facilities below their allowance allocation but at significant cost. Without the opportunity to bank the unused allowances, there would be insufficient incentive to install scrubbers, and this is captured in the no banking scenario. Compliance at many other facilities is affected as a result because the facilities that scrubbed in the baseline typically become purchasers of allowances in the no banking case.

Emission and Deposition Changes from Banking. Banking results in an intertemporal shift in emissions from 1995 to 2005. In all states, emissions fall or stay constant in 1995; however, taking into account the atmospheric dispersion of emissions, every state experiences a decline in sulfur deposition. In 2005, emissions increase in most states and in aggregate, and commensurately every state experiences an increase in deposition.

The environmental effects of banking depend on the assimilative capacity of the environment, whether there are threshold effects in environmental or public health responses to exposure, and at what level those are achieved. The environmental effects of sulfur deposition depend primarily on the stock of pollution. Hence, the early overcompliance that results from banking in the baseline scenario would seem to yield a beneficial dividend as compared to the no banking scenario because it expedites the time of ecological recovery.

Health Benefits from Banking. Following the pattern of changes in emissions due to banking, additional health benefits are $4 billion greater in 1995, offset by additional health costs of over $2 billion in 2005. The bank will be built up about twice as fast as it will be depleted, which explains much of the difference in the magnitude of these estimates—they are essentially offsetting in current value terms (absent discounting). Figures 4 and 5 illustrate the percent change in estimated health benefits that are attributable to banking in 1995 and 2005. Banking contributes to greater health benefits in every state in 1995 and to lower health benefits in 2005.
in every state in 2005. The geographic effect of banking is variable.

The dominant view regarding exposure to particulates is that concentration–response functions are linear (i.e., no thresholds) over the range in which changes will occur, so the tradeoff of exposure in the later years for less exposure in the near-term appears inconsequential. The issue is complicated by population growth, implying that more people will be exposed in the future. On the other hand, one may view benefits achieved sooner as superior to benefits achieved later, although no discounting is applied in our model.

**Cost Savings from Trading and Banking**

Aggregate compliance costs in 2005 are $1.44 billion in the no trading scenario. The costs fall to $905 million in the baseline, a decrease of 37%. These estimates compare favorably with an econometric model reported in ref 5.

In principle, banking should decrease costs. However, with perfect hindsight we find that the opportunity for banking actually led compliance costs to be higher by $651 million in 1995 and by $339 million in 2005. Banking encouraged the construction of scrubbers that appear ex post to be inefficient given changes in fuel markets after the planning and construction of these facilities. We calculate that none of the 21 scrubbers that were built in Phase I would have been built if there had not been banking and bonus allowances.

**Discussion**

The emission changes we identify only pertain to trading and banking, which are only a small part of the story with respect to the overall impact of the SO2 program. Overall, the program will result in dramatic emission reductions of nearly 50%.

Furthermore, it is important to note that the overall emission reductions might not otherwise have been achieved without the opportunity to trade and bank. The flexibility offered by these aspects of the program led to significant decreases in cost and made the program economically
affordable and politically acceptable. Finally, this analysis leaves aside entirely an evaluation of the proper level of emission reductions and the question of whether environmental resources and public health are adequately protected.

These findings do not generalize to other potential trading programs, but the questions do. In particular, one cannot be sanguine about the environmental effects of trading of NOx emissions by electric utilities. Although NOx emissions contribute to acidification and to the creation of secondary particulates in analogous fashion to SO2, abatement strategies vary greatly; so the trading of NOx allowances is unlikely to mirror the trading of SO2 allowances. Also, NOx contributes to a different set of problems, including ground-level ozone. What may generalize from the SO2 experience is the opportunity for cost savings through allowance trading. Nonetheless, public policy should remain sensitive to the environmental consequences of trading, and programs should be designed to take this into account.

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Supporting Information Available
Three appendices giving the history of emissions, allowance allocations, and trading (2 tables), Tracking and Analysis Framework documentation (text), and other results (3 tables) (9 pages). This material is available free of charge via the Internet at http://pubs.acs.org.

Literature Cited

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