

An Interim Evaluation of Sulfur Dioxide Emissions Trading

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Title IV of the 1990 Clean Air Act Amendments established the first large-scale, long-term environmental program to rely on tradable emissions permits—called “allowances” in this program—to control pollution. This program was designed to cut acid rain by reducing sulfur dioxide (SO₂) emissions from electric generating plants to about half their 1980 level, beginning in 1995. It is of interest both as a response to an important environmental issue and as a landmark experiment in environmental policy. This experiment comes at a particularly important time, since emission trading is under serious consideration, with strong U.S. backing, for use to deal with global climate change by curbing emissions of carbon dioxide (CO₂). The economic stakes in climate change surpass those in acid rain by several orders of magnitude (Intergovernmental Panel on Climate Change, 1996).

This article summarizes the results to date of our ongoing empirical analysis of compliance costs and allowance market performance under the U.S. acid rain program.¹

¹ For discussions of earlier U.S. experience with emissions trading, see Hahn and Hester (1989a, b) and National Economic Research Associates (1994, ch. 2). There is very little experience with this approach outside the United States.

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Supporting analysis and additional detail are presented and other issues are explored in Ellerman et al. (1997) and our other papers that are cited in what follows.

What is the Acid Rain Program?

Acid rain (or, more properly, acid deposition) occurs when SO_2 and nitrogen oxides (NO_x) react in the atmosphere to form sulfuric and nitric acids, respectively. These acids then fall to earth, sometimes hundreds of miles from their source, in either wet or dry form. The dominant precursor of acid rain in the United States is SO_2 from coal-fired power plants in the northeast and midwest.

These emissions are the focus of the acid rain program created by Title IV of the Clean Air Act Amendments of 1990. Title IV created a cap on utility SO_2 emissions from electric generating units, to be implemented in two phases. During Phase I, 1995 through 1999, aggregate annual emissions from the 263 dirtiest large generating units—the so-called “Table A units”—must be below a fixed cap. (In 1990 these units accounted for about 22 percent of heat input at U.S. fossil-fueled generating units and about 17 percent of capacity.) In Phase II, 2000 and beyond, virtually all existing and new fossil-fueled electric generating units in the continental United States become subject to a tighter cap on aggregate annual emissions. As the term is used here, an electric generating *unit* is a combustion device (boiler or turbine) used to power one or more electric generators. A typical generating *plant* houses several generating units, which may be of different vintages, scales, or types.

Two provisions, little noted when Title IV was debated, provide that other utility generating units can be voluntarily brought under Title IV regulation in Phase I, thus becoming, along with the Table A units, “affected units.” The “substitution” provision was intended to enable owners of Table A units to substitute less costly emission reductions from other units for reductions from the Table A units. The “compensation” provision was designed to prevent owners of Table A units from meeting their emission reduction obligations simply by reducing generation from those particular units and increasing generation from other units. Accordingly, this provision required that if generation at a Table A unit was reduced significantly, one or more non-Table A units had to be brought under Phase I regulation to compensate, and increased generation at the latter units had to offset the reduction at the Table A unit. As it happened, generation at Table A units increased substantially in 1995 and 1996.

In both Phase I and Phase II, owners of existing affected units are given fixed numbers of tradable permits, called “allowances,” each year following rules that depend primarily on historic emissions and fuel use. Each allowance entitles its holder to emit one ton of SO_2 . A small number of additional allowances are auctioned annually by the Environmental Protection Agency (EPA), with the revenues rebated to utilities roughly in proportion to their allowance allocations. New affected units must buy needed allowances from existing units or at the EPA auctions, discussed below. Each affected generating unit must deliver to EPA valid allowances sufficient to cover each year’s emissions within 30 days of year’s end or incur serious

penalties. (Emissions are continuously monitored from affected units, at an average annual cost of about \$124,000 per unit.)

~~Allowances can be bought or sold without restriction to cover emissions anywhere in the continental United States.~~ Permitting allowances to be traded freely anywhere in the United States would be a first-best policy if and only if emissions everywhere in the United States had the same marginal damages, which they plainly do not. However, unrestricted trading would be a reasonable second-best response to worries that the allowance market would otherwise be too thin if marginal abatement costs are inversely correlated with marginal damages. In this case, emissions reductions will tend to be made in the lower-cost, higher-damage places in equilibrium. Large observed reductions in midwest emissions (discussed below) suggest that this condition might be satisfied in fact, though we have seen no formal analysis of this issue.

An allowance can be used in the year it is issued or "banked" for use in any subsequent year. In the early 1990s, analysts predicted allowance prices of about \$250–350 per ton in Phase I and \$500–700 in Phase II. (The expected time-path must in fact be continuous, since arbitrage conditions and the ability to hold the allowances over time rule out a predictable upward jump in allowance prices at the start of Phase II.)

The acid rain program represents a conceptually important departure from the "command-and-control" tradition that has dominated environmental policy in the United States and abroad. This traditional approach involved prescription of either particular abatement methods, so-called "engineering standards," or maximum emission rates, so-called "performance standards," for a particular pollutant for classes (commonly, types and vintages) of emissions sources. In 1971, for instance, the EPA announced a maximum SO₂ emission rate (expressed in pounds of sulfur per million Btu of fuel burned) for new coal-fired generating units. Additional emission rate constraints, varying substantially in stringency, were placed on existing units under State Implementation Plans, but no limits were imposed on total emissions. The tradable permit approach, in contrast, focuses on total emissions, which are more directly linked to environmental damages.

Holding power generation constant, there are two basic ways to reduce SO₂ emissions from electric generating units: fuel switching, which means burning fuel with less sulfur; and scrubbing, which means operating desulfurization facilities that reduce the amount of SO₂ exiting the stack. Switching to coal with a lower sulfur content has historically raised fuel cost but involved little or no capital cost, while scrubbing involves capital costs of about \$125 million on average for a medium-sized 500 megawatt generating unit. Because of differences in location, design, and utilization rate, existing generating units differ considerably in the ease and cost with which they can switch to lower-sulfur fuel or accommodate scrubbers. Any environmental program that imposed the same standards across this heterogeneous population of pollution sources would inflate total cost and would likely impose very high and politically unacceptable costs on some utilities or regions.

Past regulatory policy typically ducked this problem by subjecting new generating units to stricter environmental controls than old units. As a result, utilities

faced strong incentives to extend the lives of their old units. By 1985, 83 percent of power plant SO₂ emissions came from units that did not meet the 1971 SO₂ emission rate standard for new units.² Any acid rain program would have had to deal with these old units, but their designs and site characteristics varied enormously, and, as a consequence, so did the costs of reducing their SO₂ emissions. One important reason why Congress adopted the nontraditional approach in Title IV was that because of this heterogeneity, there seemed to be no workable “command-and-control” solution to the acid rain problem.³

Allowances were given to utilities rather than sold because there was no way that a sales-based program could have passed Congress. Indeed, the only politically live alternative to a simple grant of allowances was to impose an electricity tax that would have forced the customers of “clean” utilities to help pay the clean-up costs of “dirty” utilities. The complex statutory provisions that allocate allowances to individual generating units show clear evidence of rent-seeking, but do not provide strong support for any simple model of government decision-making (Joskow and Schmalensee, forthcoming). On the whole, the states that mined or burned substantial amounts of high-sulfur coal, which had successfully resisted acid rain legislation during the 1980s, did less well in the allowance allocation process than their earlier success on this issue would have suggested.

What Happened to Sulfur Dioxide Emissions?

Most of the analysis that follows is based on data at the generating unit level for 1995 and 1996, the first two years this program constrained emissions, and earlier years, and on allowance market data beginning in 1992. Our estimates rely heavily on the EPA’s National Allowance Data Base (NADB), Supplemental Data File (SDF), Allowance Tracking System (ATS), and Emissions Monitoring System (EMS).⁴

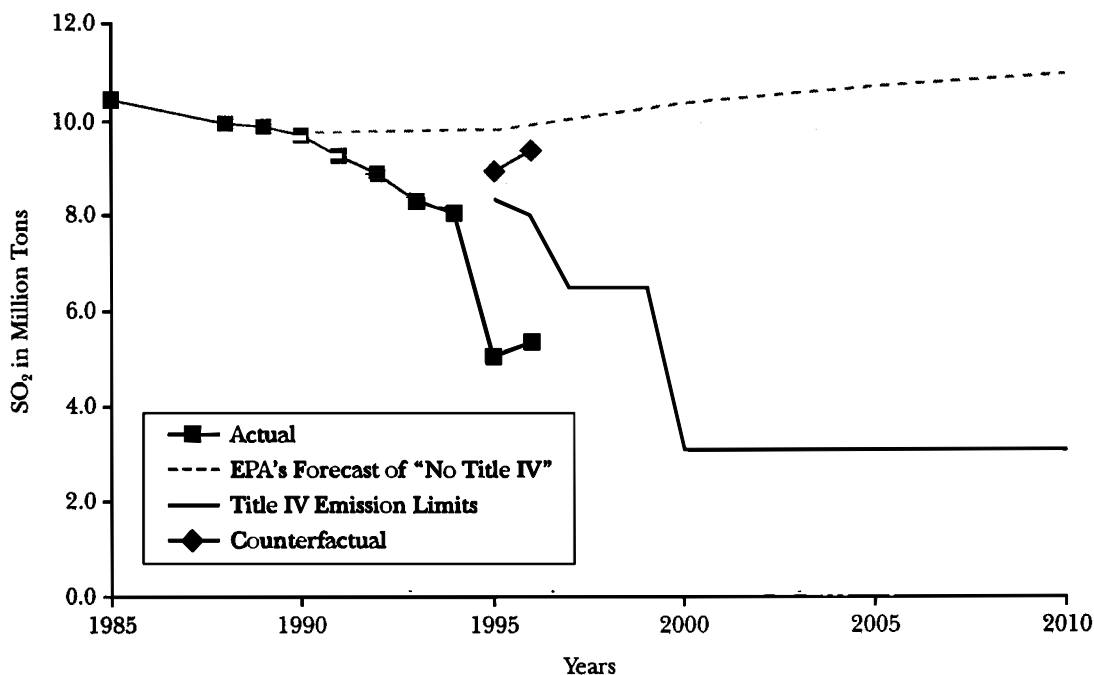
Figure 1 shows the basic pattern of aggregate emissions from units that were affected under Phase I in both 1995 and 1996. (There were 413 such units; they accounted for 95 percent of emissions from all affected units in 1995 and 98 percent in 1996.) Aggregate SO₂ emissions, shown by the line with squares, declined substantially from 1990 through 1994. The dashed line shows the level of SO₂ emissions that the EPA had forecast for this period if Title IV had not passed. The solid line shows the emission limits imposed by Title IV. About 80 percent of the pre-

² Calculated by the authors from EPA’s National Allowance Data Base. These units were too old to be bound by the 1971 standard.

³ The origins and political economy of this program are discussed in more detail in Joskow and Schmalensee (forthcoming) and in Stavins’s article in this issue.

⁴ In addition, we have relied on the trade press, earlier studies of compliance by the Electric Power Research Institute (EPRI), a mail survey of affected utilities that we conducted in the summer of 1996 seeking information about compliance strategies and associated costs (replies covered 37 percent of affected capacity in Phase I), and many telephone interviews with personnel from government agencies, electric utilities, and participants in allowance markets.

Figure 1
SO₂ Emissions, Caps and Forecasts for Phase I Units



Source: Derived from Pechan (1995), EPA's EMS and ATS, and EPA (1996).

Phase I emission decline reflected the expansion of the market area served by low-sulfur coal from the Powder River Basin in northeast Wyoming (Ellerman and Montero, 1996). This expansion mainly reflected declines in delivered prices driven by reductions in rail rates, which reflected in turn the continuing productivity benefits of rail deregulation and the introduction of competition into the haulage of coal from the Powder River Basin.

Figure 1 also shows that emissions dropped sharply in 1995 to about 5.3 million tons, 39 percent below total allowances issued or auctioned for that year. Similarly, 1996 emissions were 33 percent below total vintage 1996 allowances. The 6.2 million vintage 1995 and 1996 allowances not needed to cover emissions in these two years were banked for future use. There are two plausible explanations for the dramatic overcompliance seen in these years.

The first explanation involves intertemporal trading and optimization. Allowances have generally been expected to be more expensive in Phase II than in Phase I, so that even when the Phase I constraint on total emissions is not binding, it may be rational to reduce emissions on the margin and save the allowances thus freed up for use in Phase II. This point was widely discussed in the early 1990s, and many analysts argued that some banking of this sort would be efficient throughout Phase I.

For it to be efficient to carry allowances from any period t to period $t + 1$ in a riskless world, the allowance price must rise at the rate of interest between those periods. In addition, the allowance price must equal operating units' short-run

marginal abatement cost.⁵ Thus if marginal costs of abatement are non-decreasing, emissions from regulated units must fall along an efficient path with banking from period t to period $t + 1$. At some time T^* in Phase II, the "allowance bank" will be exhausted, and thereafter the allowance price must equal marginal compliance cost. In a riskless world, arbitrage would then ensure that the allowance price at any time t before T^* would equal the marginal cost of compliance at T^* , discounted back to t . In the real world, of course, future abatement costs and market conditions are uncertain, neither T^* nor marginal cost at that time are known for certain, and there is a time-varying "convenience yield" provided by holding allowances, as is the case with other commodities (Williams and Wright, 1991; Bailey, 1998). All else equal, the existence of a positive convenience yield reduces the expected rate of allowance price increases during a period of banking.

The second explanation for substantial overcompliance early in Phase I is that in the aggregate the market underestimated how declines in rail rates would increase the penetration of low-sulfur Powder River Basin coal, and, as a consequence, overinvested in scrubbers and signed long-term contracts for too much low-sulfur coal. This disequilibrium explanation is consistent with the fact that the actual level of banking in 1995 and 1996 far exceeded earlier predictions and with other evidence discussed below.

While only the 263 generating so-called "Table A units" were required to be regulated in Phase I, a much larger than expected number of generating units "volunteered" for such regulation: 182 units in 1995 and 168 in 1996 (with 150 volunteering in both years).⁶ As noted above, the provisions under which these units opted into Phase I were designed to allow substitution of lower-cost abatement at non-Table A units for higher cost abatement at Table A units. However, while some cost-reducing substitution did occur, and we estimate that the volunteers reduced their emissions in aggregate by around 200,000 tons in both 1995 and 1996, our analysis indicates that factors other than abatement cost differences had more impact on the decision to volunteer a unit for Phase I regulation (Montero, 1997a). The process of allocating allowances to volunteers based on past emissions inevitably created adverse selection problems, as units with high past emissions for transitory reasons were given incentives to opt-in to obtain valuable allowances.⁷ We estimate that these "substitution and compensation" units received in aggregate 263,000 more allowances in 1995, and 365,000 more in 1996 (20 and 30 percent of their total allocations in these years, respectively), than they would have needed to cover their emissions in the absence of Title IV. In addition, volunteers were exempted from certain NO_x regulations that would have been very costly for some units. Current emissions at these units were reduced somewhat, but the issuance of

⁵ Except, of course, for the obvious inequalities that occur for units reducing emissions by either zero or by the maximum possible in the short run.

⁶ In contrast, a much-discussed provision aimed at inducing non-utility sources of SO_2 emissions to "opt-in" to the acid rain program had produced only seven industrial opt-in units at two locations by March 1997. See Atkeson (1997) for a discussion.

⁷ Montero (1997b) discusses the optimal design of voluntary programs of this sort.

excess allowances implies a more than compensating increase of emissions elsewhere or in the future. In the end, utilities' substantial use of the "substitution and compensation" provisions did little to reduce compliance costs and caused some increase in total lifetime SO₂ emissions.

How Were Emissions Reduced?

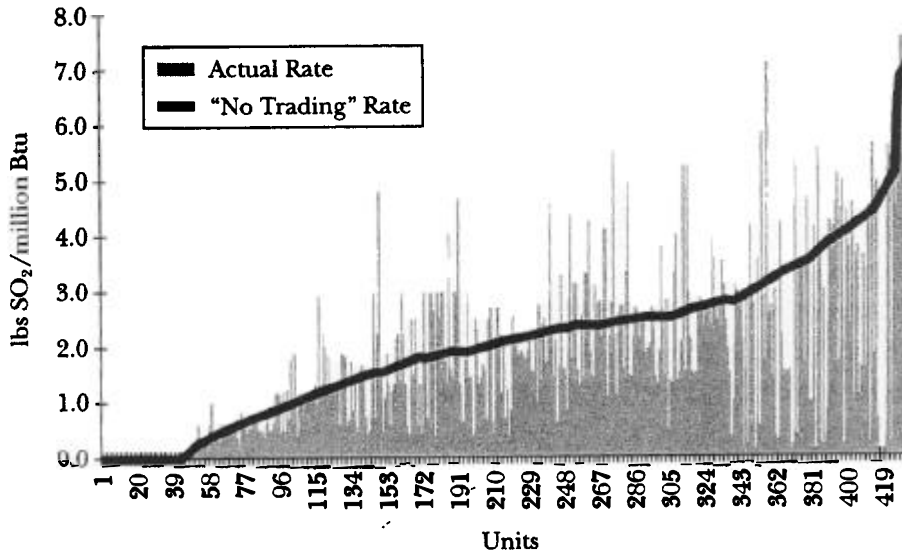
To analyze the extent to which the emissions reduction in 1995 and 1996 was attributable to Title IV, it is necessary to estimate what SO₂ emissions would have been for Phase I units in those years in the absence of Title IV. Our rough estimate of each Phase I unit's 1995 or 1996 counterfactual emissions is the product of its 1993 emissions rate, measured by SO₂ emitted per unit of heat input, times its actual 1995 or 1996 heat input.⁸

Figure 1 shows that total 1995 and 1996 counterfactual emissions for these Phase I units, indicated by the two diamonds, were above actual 1993 emissions by 7.7 and 12.8 percent, respectively. As these differences reflect comparable increases in heat input at affected units, it is clear that compliance with the SO₂ standard was *not* achieved by reducing utilization of units subject to Phase I regulation. Counterfactual emissions were 0.5 and 1.2 million tons above the Phase I cap in 1995 and 1996, respectively, and roughly four million tons above actual emissions in both years. One-quarter of the total reduction from the counterfactual in these years occurred in Ohio, and 90 percent occurred in the nine high-emissions states extending from Pennsylvania and West Virginia west to Missouri and south to Tennessee and Georgia.

Comparing actual and counterfactual emissions for each unit, we find that the 27 "Table A" units that began operating scrubbers in 1995 or 1996 accounted for about 45 percent of the total reduction in emissions. Almost two-thirds of the reduction due to scrubbing in 1995 and 1996 was contributed by seven units at three large plants. Fuel switching, almost entirely to lower-sulfur coal (rather than, say, to natural gas), accounted for 55 percent of total reductions. While switching to Powder River Basin coal accounted for a large fraction of the reductions in emissions between 1990 and 1993, it only accounted for about 13 percent of the difference between actual and counterfactual 1995 emissions at Phase I units. Switching to lower-sulfur (not necessarily low-sulfur) eastern or midwestern coal was much more important. Finally, even though the "substitution and compensation" provisions were much more heavily used than had been anticipated, the Table A units accounted for at least 95 percent of the emission reductions in both 1995 and 1996.

⁸ The ratio of 1995 and 1996 heat input to 1993 heat input varied relatively little across Phase I units, but did tend to be higher than average for scrubbed units. This pattern casts some doubt on the implicit assumption that heat inputs at affected units were not influenced by Title IV. We considered an alternative counterfactual that avoids this problem (using heat inputs proportional to 1993 inputs and scaled up to match the 1995 and 1996 totals) and obtained results qualitatively similar to those reported in the

Figure 2
Effect of Trading: 1996



Source: Derived from Pechan (1995), EPA's EMS, and EPA (1996).

One can learn about the extent to which compliance strategies took advantage of the flexibility allowed by Title IV by comparing units' actual emission rates per unit of heat input with what those rates would plausibly have been in the absence of emissions trading. Figure 2 provides such a comparison for 1996. (The corresponding graph for 1995 shows a very similar pattern.)

The 431 units covered by Title IV in 1996 are arrayed along the horizontal axis from lowest to highest estimated "no-trading" emission rate. We estimate each unit's no-trading rate as the smaller of its unconstrained emissions rate, which we again take to be its actual 1993 rate, and the maximum legal 1996 emissions rate under a hypothetical no-trading acid rain policy. We assume that this hypothetical policy differs from Title IV only in that allowances cannot be transferred among units, and we take as given each unit's actual allocation of vintage 1996 allowances and its actual fuel use in 1996. Thus each unit's maximum legal emissions rate in this no-trading regime is equal to the ratio of its 1996 allowances (multiplied by 2000 to convert to pounds) to its 1996 fuel use in millions of Btus. The ascending heavy dark line shows the estimated no-trading emissions rates.⁹ The grey vertical bars show each unit's actual 1996 emission rate. While there is some tendency for units with higher no-trading emission rates to have higher actual emission rates,

⁹ The 40-odd units with zero no-trading emissions rates that are shown on the left of the horizontal axis were retired or otherwise off-line in 1996. On the right, high no-trading rates reflect either the receipt of extra allowances (usually as a reward for scrubbing) or a substantially lower heat input in 1996 than

the correlation is far from perfect.¹⁰ Figure 2 shows that utilities took advantage of the flexibility provided by Title IV to employ a wide variety of unit-specific compliance strategies, something not possible under traditional command-and-control regimes.

Some units reduced emissions in both 1995 and 1996 to well below their allowance allocations and either transferred allowances to other units or held them for future use, while others reduced emissions relatively little and acquired allowances to be in compliance. About 10 percent of 1995 total emissions (534,000 tons) and 13 percent of 1996 total emissions (689,000 tons) were covered by allowances acquired or transferred from other units, while more than one-third of vintage 1995 and 1996 allowances were banked for future use. Emissions exceeded allowance allocations at 98 generating units in 1995 and 109 generating units in 1996; these were located in 18 of the 24 states with Phase I units. The heterogeneity of unit-specific response strategies depicted in Figure 2 indicates that Title IV was an economically significant departure, as well as a conceptually significant departure, from the traditional "one size fits all" U.S. approach of setting unit-level emission rate standards.

What Happened in Allowance Markets?

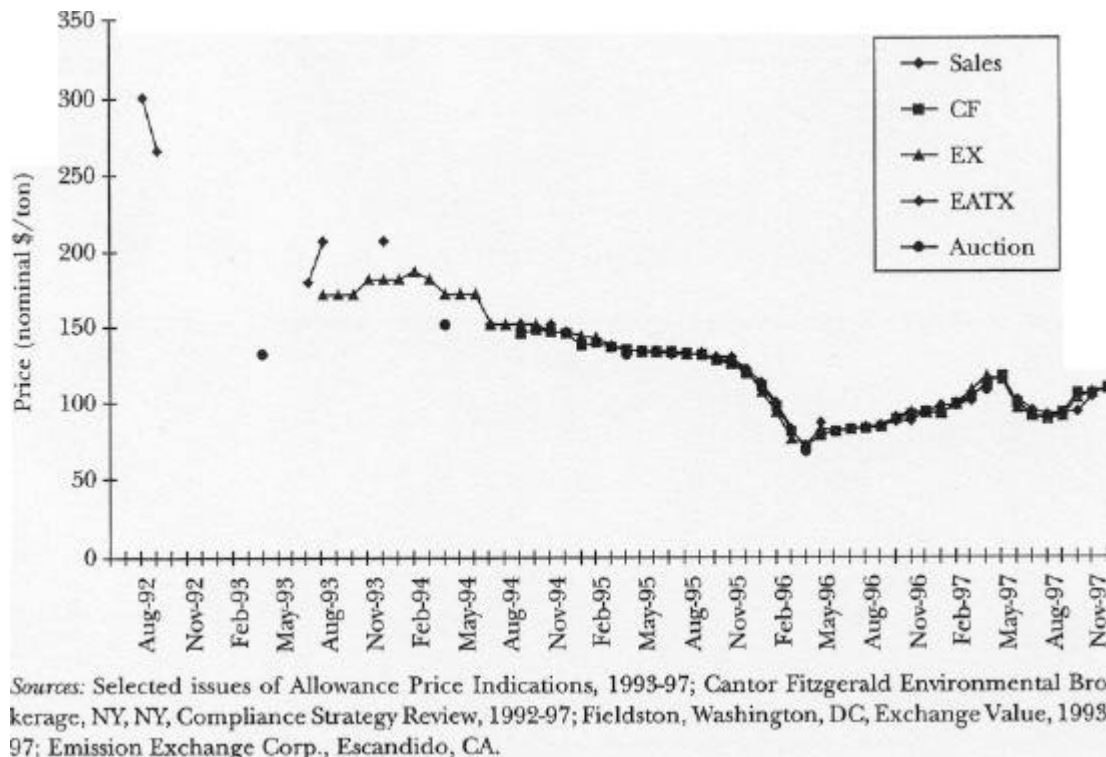
Figure 3 displays historical information on the pricing of vintage 1995 allowances (in 1995 and earlier) or "current vintage" allowances, where "current vintage" allowances are all those that can be used to offset current emissions. During 1996, vintage 1995 and 1996 allowances are "current vintage" and thus perfect substitutes; vintage 1997 allowances are also "current vintage" during 1997.¹¹ These data come from five sources: trade press reports; price indices from three private market-making organizations, namely the Emissions Exchange (EX), Fieldston (EATX) and Cantor Fitzgerald (CF); and the EPA's annual March auctions. As directed by the statute, the EPA has implemented a discriminatory auction scheme, in which winning bidders pay what they bid for the small number of allowances EPA auctions each year. The circles in Figure 3 show the clearing prices (lowest winning bids) for vintage 1995 (for 1993–1995) or current vintage (for 1996 and 1997) allowances.

The EPA announced allowance allocations in early 1992 and promulgated associated regulations to permit affected sources to engage in trading and to develop price information before the 1995 compliance deadline. The first allowance trans-

¹⁰ Using the 413 generating units affected by Title IV in both 1995 and 1996, let $r(t, t')$ be the correlation between emissions rates in years t and t' . Stable pre-Phase I operating patterns are revealed by values of $r(1988, 1989)$, $r(1989, 1990)$, $r(1990, 1991)$, $r(1991, 1992)$, and $r(1992, 1993)$ that all exceed 0.93. Perhaps because of utilities' preparations for the start of Phase I, $r(1993, 1994)$ falls to 0.89. Reflecting implementation of heterogeneous compliance strategies, $r(1995, 1994)$ falls to 0.72, and $r(1993, 1995)$ is only 0.64. Because compliance strategies are relatively stable, $r(1996, 1995)$ equals 0.91.

¹¹ This section is based on Joskow, Schmalensee, and Bailey (forthcoming).

Figure 3
Allowance Prices, 1992-97 (1995 or Current Vintage)



Sources: Selected issues of Allowance Price Indications, 1993-97; Cantor Fitzgerald Environmental Brokerage, NY, NY, Compliance Strategy Review, 1992-97; Fieldston, Washington, DC, Exchange Value, 1993-97; Emission Exchange Corp., Escandido, CA.

actions were reported in the trade press in mid-1992 at prices of \$300 and \$265 per allowance—roughly in line with expectations at that time. The March 1993 EPA auction produced a clearing price of \$131 for vintage 1995 allowances. This result was dismissed at the time as an aberration or a reflection of defects in the auction's design, though, as Figure 3 makes clear, it indicated correctly that earlier projections of Phase I allowance prices were too high. For the remainder of 1993, the few private transactions reported and the Emissions Exchange allowance price index seemed to support the view that the auction results were misleading, though the private transactions pointed to prices in the \$150–\$200 range rather than the \$250–\$300 range.

EPA's second auction, in March 1994, cleared at \$150 for vintage 1995 allowances, still noticeably below the EX price. Soon thereafter, however, the EX price fell to match the auction price, and the Emissions Exchange (EX) series was validated by price series published by Fieldston (EATX) and Cantor Fitzgerald (CF), two other market-makers. The March auction results in 1995, 1996, and 1997 are virtually identical to the contemporaneous private market prices reflected in these three series.

Figures on trading volume also suggest the emergence of an efficient allowance market, obeying the law of one price, around the middle of 1994. We estimate that 130,000 allowances had been traded on the private market by the end of March

1993, and an additional 226,000 traded in the period from April 1993 to March 1994.¹² Private market volumes for the next three April-March years were sharply higher: 1.6 million, 4.9 million, and 5.1 million allowances, respectively. In contrast, volume in the annual EPA auction has never exceeded 300,000 allowances. There is no obvious standard against which to evaluate these volumes, of course, but the nearly 20-fold increase in the two years after mid-1994 was clearly substantial. It is also worth noting that this increase could not have occurred if the EPA had not implemented Title IV with the intent and effect of keeping transactions costs low—another departure from tradition.

Data from the EPA auctions add a final bit of support to the view that an efficient allowance market emerged as the 1995 Phase I compliance date approached. In the two auctions held in March 1993, average winning bids were 11.5 and 20.6 percent above the lowest winning bids. In the three auctions held in March 1994, the differences between average and lowest winning bids were between 5.7 and 6.4 percent. In the nine subsequent auctions through March 1997, no such difference exceeded 3.4 percent, and all but two were below 2.4 percent. These data are consistent with strong constraints on bidding imposed by a well-developed private market.¹³

When the 1990 Clean Air Act Amendments were under consideration, opponents of the tradable allowance approach argued that the heavily regulated electric power industry would be unlikely to trade in a market for SO₂ emissions. They contended that publicity-shy utilities would be reluctant to buy “licenses to pollute” and that the state public utility commissions would discourage interstate trading.¹⁴ In fact, as of January 1996 only 15 state public utility commissions had explicitly addressed the regulatory treatment of allowance transfers by generic order or informal guideline. Interstate trading does not seem to have been deterred, however. By January 1996, allowances had been transferred across the borders of all 24 states with Phase I affected units and of 10 of the 23 states with only Phase II units. Interviews with staff of all public utility commissions that had not addressed this issue indicated that the main reason guidance had not been issued was that no request for it had been received.

¹² To obtain the trading volume figures in this paragraph, we excluded intra-utility transfers (including intra-holding-company transfers). Our estimates understate private market activity by excluding unrecorded allowance transfers, unexercised options, and trading in allowance futures, all of which seem to have risen over time, particularly during and after 1995.

¹³ Joskow, Schmalensee, and Bailey (forthcoming) discuss the criticisms of the design of the EPA auction that have been advanced by Cason (1993, 1995) and Cason and Plott (1996). Two points are central. First, the critics model the EPA auction as involving purely private values, thus completely ignoring the robust private market that has served since around mid-1994 to provide a common value for allowances. Second, the critics' main theoretical argument is that utilities that voluntarily offer to sell allowances on the EPA auctions have incentives to understate their reservation prices. In fact, most offers to sell have involved reservation prices well above market-clearing levels, and only a trivial number of voluntarily-offered allowances have been sold on the EPA auctions.

¹⁴ This paragraph is based on Bailey (1996).

How Much Did It Cost?

We have studied the costs of compliance in detail for 1995; Ellerman et al. (1997) provides details on sources and methods. We find the total (annualized) cost of reducing emissions by 3.9 million tons (relative to the counterfactual) in 1995 to have been about \$726 million. (All cost figures include annualized capital costs, along with increases, if any, in operating and fuel costs.) This is an average cost of \$187 per ton of emissions reductions, or about \$210 per ton on average if emissions reduced at no cost are excluded from the total. (These no-cost reductions all involved switches to low-sulfur Powder River Basin coal that also lowered delivered fuel price.) These per-ton abatement cost figures are at the low end of the range of earlier estimates, which varied from \$180 to \$307 per ton of emissions reduction for reductions between 3.1 and 4.4 million tons. We estimate emissions reduction through switching to more expensive lower-sulfur coal have cost \$153 per ton of emissions reduction on average, while scrubbing costs \$265 per ton on average, with considerable variation around both these averages.

There is no shortage of anecdotal evidence that utilities have made good use of the flexibility provided by Title IV, and it is natural to ask how much money this has saved. However, it is unclear what sort of hypothetical command-and-control policy could most instructively be compared with actual performance under Title IV. We have estimated that Title IV saved on the order of 25–34 percent as compared to a regime with the same allocation of allowances to generating units but no ability to transfer allowances from one generating unit to another by trading or intra-company reallocation. This is a substantial dollar saving—on the order of \$225 million to \$375 million per year—but lower in percentage terms than most savings estimates in the literature comparing actual command-and-control policies to ideal tradeable permit regimes (Oates, Portney and McGartland, 1989; Tietenberg, 1985, ch. 3; 1992, p. 403). Perhaps this is because we have chosen a hypothetical alternative that is less inefficient than most actual command-and-control policies or because, as we next discuss, expectation errors prevented cost minimization under Title IV.

Why Have Allowance Prices Been So Low?

Much of the story in the early years of allowances trading was the dawning realization that allowance prices early in Phase I were going to be only around \$100, well under half of what had been expected just a few years earlier. Both opponents and supporters of tradeable permits have advanced explanations for this result—but both are probably wrong.

Opponents of the tradeable emissions approach commonly attributed the low allowance prices to some defect in allowance markets, but they have failed to specify what these market defects are or how they have pushed prices down. On the other side, supporters of tradeable permits would be gratified if the difference between

actual and expected allowance prices mainly reflected unanticipated innovations that greatly reduced compliance costs. There certainly was some induced innovation. For example, the observed per-ton cost of scrubbing in 1995 was substantially below earlier estimates, and our investigation indicates that this difference reflected unanticipated improvements in instrumentation and controls that reduce personnel requirements, innovative sludge removal techniques, and higher than expected utilization of scrubbed units (which reduces capital cost per ton of sulfur removed). Moreover, new ways were found to adapt midwestern boilers to blends of local and Powder River Basin coals. Although such adaptation was underway prior to 1990, it may well have been accelerated by the passage of Title IV. However, the dramatic gap between actual and expected allowance prices is simply too large to be accounted for by the observed technological improvements.

A more plausible explanation for the very low price of allowances begins by noting that compliance decisions generally had to be made well before the start of 1995. In particular, decisions to build scrubbers required commitments in 1992–93, when information about prices of allowances was highly imperfect. Most of the respondents to our 1996 survey (see note 4, above) who had elected to scrub indicated that expectations of allowance prices in the \$300–400 range were “very important” in the choice of scrubbing. Though switching does not require as much advance planning as scrubbing, many utilities signed long-term contracts for low sulfur coal in the 1992–94 period at premium prices reflecting expected coal market conditions in Phase I.

However, it is now clear that market participants considering scrubbing or long-term contracts for lower-sulfur coal underestimated the extent to which declines in rail rates would make it possible to reduce SO₂ emissions reductions at zero or negative cost by switching to Powder River Basin coal and the extent to which falling delivered prices of that coal would drive down the price of lower-sulfur coal from the east and midwest. Thus, until mid-1994 or so, they overestimated allowance prices during at least the early part of Phase I. As a result, there was overinvestment in scrubbers, and long-term contracts were signed for too much lower-sulfur coal from the east and midwest—some at very high prices. Indeed, a number of respondents to our 1996 survey identified substantial capacity for which they had reversed an initial decision to scrub; a third of these pointed to “low allowance prices” as a reason for reversal, and two-thirds pointed to a fall in low sulfur coal prices relative to scrubber costs.

Once a scrubber is built, however, the decision to run it or not turns on a comparison between the short-run marginal operating cost of using the scrubber to reduce emissions of sulfur by a ton, roughly \$65 per ton on average, and the cost of the allowance that would need to be purchased if the scrubber were not run. Because of overinvestment in compliance, the short-run marginal cost of abatement curve was well below the long-run marginal cost curve during 1995 and 1996. A short-run marginal cost of abatement curve that is lower than it would be in long-run equilibrium is consistent with both unexpectedly low allowance prices in the short run and unexpectedly high banking of allowances. This pattern is at least qualitatively consistent with intertemporal equilibrium as well: more banking today

postpones the date at which the bank is exhausted (T^* above) and thus reduces the present value of expected marginal abatement cost at that date. It is also consistent with the 6.2 percent increase in emissions from 1995 to 1996 by units that were Phase I affected in both years, a change that can be interpreted as movement toward an efficient equilibrium time-path of emissions but not easily as movement along such a time-path.

What Have We Learned?

Economists have argued for decades that, where the tradable permit approach can be used, it is superior to command-and-control environmental regulation (Tietenberg, 1985). The U.S. acid rain program appears to prove this argument correct in practice. Not only did Title IV more than achieve the SO_2 emissions goal established for Phase I, it did so on time, without extensive litigation, and at costs lower than had been projected. Some of the credit must be attributed to the lower rail rates that widened the area within which low-sulfur Powder River Basin coal could be economically used. Nonetheless, it is important to note that few command-and-control environmental programs, if any, have ever succeeded on all these dimensions.

Viewing the acid rain program as a more general experiment in environmental policy, it is too early to have learned all the lessons it will eventually teach us. Still, we believe several important lessons do follow from our experience to date with Title IV.

First, we have learned that large-scale tradable permit programs can work roughly as the textbooks describe; that is, they can both guarantee emissions reductions and allow profit-seeking emitters to reduce total compliance cost.

Second, one can expect a tradable permit program both to produce surprises and to adapt reasonably efficiently to surprises produced elsewhere in the economy. The big surprise here was the rapid expansion of the market area of Powder River Basin coal, and delayed recognition of this change apparently led to overinvestment and excess emissions abatement. But the market did react to the information contained in allowance prices, and orders for some scrubbers were canceled. The provisions for banking allowances then ensured that emissions reductions that had been reduced in cost by earlier investments were made, even though they were not required by the statute. It is hard to imagine any command-and-control regime adapting as sensibly to such an important exogenous event.

Third, efficient, competitive markets for tradable allowances may take time to develop, and the speed of development may be sensitive to some elements of program design. For example, the allowance auctions that the EPA was required to conduct seem to have facilitated both the price discovery process and the development of the allowance market. While larger auctions with a different design might have done better, only experience with other new programs will help to resolve this point.

Fourth, nothing in the experience with Title IV suggests that tradeable permit

programs are a magic tool than can solve any environmental problem at negligible cost. It is clear that one could not use a tradeable permit approach of the sort described here to deal with, for example, an isolated source of toxic emissions with only local effects, since there would not be enough participants to make a market function. Moreover, Title IV rests on accurate emissions monitoring and strict enforcement of the property rights involved. Monitoring and enforcement are likely to pose more serious barriers to the implementation of an international tradeable permit system aimed at emissions of carbon dioxide and other greenhouse gases (Schmalensee, forthcoming).

The Title IV experience to date has demonstrated that the tradable permit approach is a very valuable policy tool that has proven itself superior to traditional methods for dealing with acid rain. However, actual markets do not always perform with frictionless perfection, particularly when they must guide long-lived investments made under conditions of real-world uncertainty.

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