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A. Denny Ellerman[1]

INTRODUCTION

The acid rain provisions of the 1990 Clean Air Act Amendments, included in Title IV, required fossil-fuel-fired electricity generating units to reduce sulfur dioxide (SO_2) emissions by 50% in two phases. In the first, known as Phase I and extending from 1995 through 1999, generating units of 100 MW^e of capacity and larger, having an SO_2 emission rate in 1985 of 2.5 lbs. per million Btu (#/mmBtu) or higher, were required to take a first step and to reduce SO_2 emissions to an average of 2.5 #/mmBtu during these transitional years. Phase II, which began in 2000 and continues indefinitely, expanded the scope of the program by including all fossil-fuel-fired generating units greater than 25 MW^e and increased its stringency by requiring affected units to reduce emissions to an average emission rate that would be approximately 1.2 #/mmBtu at average annual heat or Btu input in 1985-87, and that would be proportionately lower for increased total fossil-fuel fired heat input.[2]

The behavior of affected units in Phase I has provided the answers to many questions about how tradable permit systems would work in practice: for instance, how electric utilities would use allowances and whether reasonably efficient allowance markets would develop. It has also been possible to answer questions about environmental effectiveness, patterns of abatement, opt-in behavior, cost savings, and

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[1] Ellerman is executive director of the Center for Energy and Environmental Policy Research (CEEPR) at MIT and senior lecturer in the Sloan School of Management. The author is indebted to Paul Joskow for comments on an earlier draft, to Curtis Carlson and Byron Swift, who commented on the paper at the EPA workshop on market-based mechanisms at which the paper was first presented, and to Brice Tariel and Florence Dubroeucq for very capable research assistance. Funding by EPA STAR grant award #R-82863001-0 is gratefully acknowledged.

[2] The nation-wide Phase II cap on SO_2 emissions is 8.9 million tons, which is approximately the product of total baseline (average 1985-87) heat input and the emission rate target of 1.2 #/mmBtu. Since the cap is fixed, higher total heat input necessarily implies a lower average emission rate, and vice versa.

innovative activity associated with cap-and-trade programs.[3] Yet, the answers to some of these questions were necessarily incomplete, while other questions could not be addressed until Phase II began, such as: How much additional abatement would be provided by the four-fold increase in coverage and the tighter cap? How would the allowances banked in Phase I be used during Phase II? Was the degree of over-compliance in Phase I, which led to the accumulation of a large allowance bank, even reasonably optimal? Do new generating units, who receive no allowances, face any barriers to entry caused by the need to acquire allowances in the market? And finally, what will it all cost when the Phase II cap is fully phased in? This paper provides tentative answers to these questions based on the analysis of data from the first two years of Phase II.

THE DISTRIBUTION OF ABATEMENT

Phase 1 and Phase II units

Any analysis of abatement and compliance must distinguish between those units for which 2000 was only the sixth year of being subject to the requirements of Title IV and those for which 2000 was the first year.[4] Table 1 shows the relevant statistics for these two groups of units for the year 2001.

Table 1. Title IV Compliance Behavior, 2001

	Phase I Units (374 Units)	Significant Phase II Units (1,420 Units)	Total (1,794 Units)
Heat Input (trillion Btu)	6,007 (24%)	18,730	24,737
Emissions (000 tons SO_2)	4,041 (38%)	6,571	10,612
Emission Rate (lbs SO_2/mmBtu)	1.35	0.70	0.86
CF Emissions (000 tons SO_2)	9,304 (55%)	7,622	16,926
Abatement (000 tons SO_2)	5,263 (83%)	1,051	6,314
Allowances (000 tons SO_2)	2,914 (32%)	6,199	9,113
Banking (000 tons SO_2)	(1,127) (75%)	(372)	(1,499)

[3] The principal works evaluating compliance behavior in Phase I are Burtraw (1996), Carlson et al. (2000), Ellerman et al. (2000), Joskow et al. (1998), Montero (1999), Popp (2001), Schmalensee et al. (1998), Swift (2000), and Swift (2001). Ellerman (2003) provides an update that includes the first years of Phase II and Ellerman et al. (2003) provide a more general treatment that includes other emissions trading programs.
[4] About 100 of the Phase II units opted into and out of Title IV in one or more years of Phase I, but none of these units were continuously affected until 2000.

Three hundred seventy-four electrical generating units were subject to Title IV during all five years of Phase I, including 263 units that were mandated to be subject to Title IV beginning in 1995 and another 111 units that voluntarily opted into Phase I for all five years. A total of nearly 4,000 unit accounts were subject to Title IV requirements in 2000 and 2001, but many of these were for units that were yet to be built and about 1200 generated little electricity and virtually no emissions. For the purpose of analyzing the Phase II response, inclusion of these units provides little information about compliance behavior since they account for less than 2% of fossil-fuel heat input and less than 0.2% of emissions.[5] Instead, and unless otherwise stated the analysis below is based on the 374 Phase I units and 1420 Phase II units that can be considered significant either because of their generation or their emissions. By definition, the Phase II units are smaller and lower emitting units, but they accounted for approximately 45% of 2001 counterfactual emissions and they received 68% of the allowances.

While the Phase II units account for the majority of allowances and heat input (and therefore generation), they account for a relative small part of the abatement that can be attributed to Title IV. The reduction of SO_2 emissions in 2001 due to Title IV is 6.3 million tons of which five-sixths occurred at the Phase I units. As a group, these units have reduced emissions by 57%, while the comparable percentage for the Phase II units is 14%. As a result, the share of emissions attributable to the Phase I units, the “big dirties,” has declined from approximately 55% of the national total to 38%.

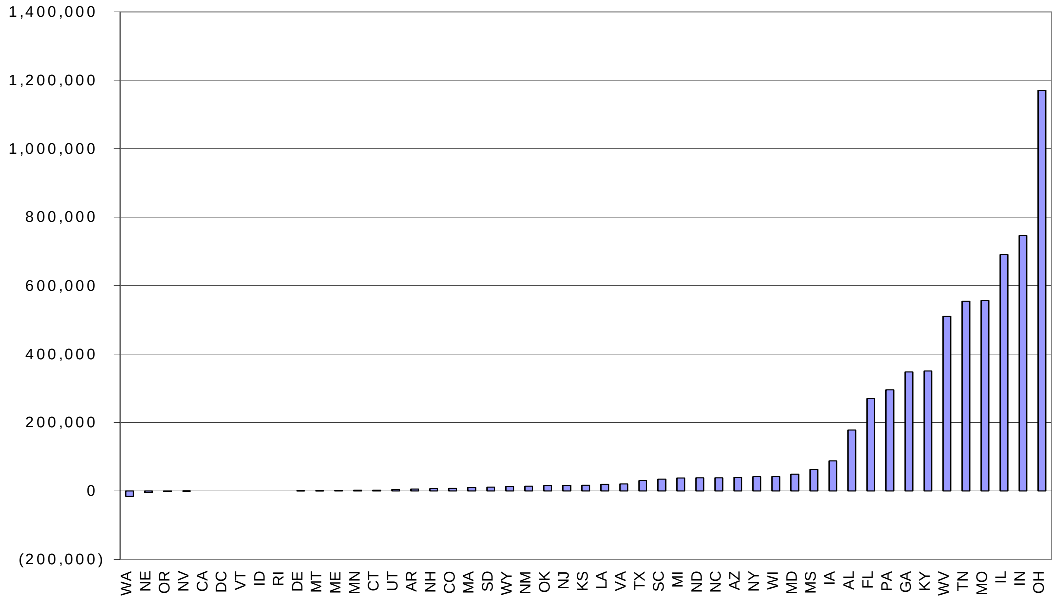
As of 2001, both Phase I and Phase II units are relying upon the accumulated Phase I bank of allowances to cover emissions that are higher in the aggregate than the 2001 allowances allocated to these two categories. The use of the bank is however much greater for the Phase I units; their emissions are about 39% higher than the aggregate allowance allocation for the Phase I units while the comparable number for the Phase II units is 6%.

[5] Technically, the criteria for inclusion as a significant unit was having heat input greater than 1 x 10^{12} Btu in two of the seven years, 1995-2001, or heat input greater than 5 x 10^{12} Btu in any one of those years. For a unit with a heat rate of 10,000 Btu/kwh, heat input of 1 x 10^{12} Btu would generate approximately 100,000 Mwh in a year, which would imply a 11% capacity factor for a 100 MW unit.

The Geographic Distribution of Abatement

Figure 1 show the geographical distribution of abatement in 2000.

Figure 1. Title IV Emission Reduction by State, 2000 (tons SO_2)



Eleven states (OH, IN, IL, MO, TN, WV, KY, GA, PA, FL, and AL) account for 90% of national abatement. Excluding the three southeastern states of GA, FL, and AL, 77% of the abatement is occurring in the Mid-west. This geographic concentration of abatement in the Mid-west reflects the predominance of the Phase I units in this region. Virtually all of the Phase I units are located east of the Mississippi River and the heaviest concentration of emissions prior to enactment of Title IV was in the Mid-west.

Since Title IV did not require abatement in any specific geographic location, one might ask: Why did the abatement occur where it was desired? The increased availability and attractiveness of lower sulfur coals in the Midwest provides part of the answer, but an equally important cause is the changed incentive structure of cap-and-trade programs. Deep abatement technologies, such as scrubbers, are more economic at units where a lot of sulfur can be removed, that is, at large units burning high sulfur coal, which in this instance were located in the Midwest. When the owners of affected units must pay a price (in the form of an allowance surrendered) for every ton of emissions, these large and high emitting units will offer the most attractive locations for scrubbers. In fact, 23 of the 30 retrofitted scrubbers installed in response to Title IV are located in the Midwest.

By Abatement Technique

Table 2 provides a breakout of emissions reductions in 2001 by abatement technique, that is, whether by scrubbing or switching to lower sulfur fuels.

Table 2: 2001 Emission Reduction by Technique and Fuel

000 tons	Phase I Units	Phase II Units	Total
Scrubbing	2,048	263	2,311
Fuel Switching	3,215	788	4,003
Total	5,263	1,051	6,314

Scrubbing accounts for approximately 37% of the abatement in 2001 and virtually all of this abatement (1,993,000 tons) comes from new scrubbers installed on 30 Phase I units as a result of Title IV.[6] These thirty units, located primarily in the Midwest and constituting 3% of the generating capacity and 4% of the 2001 heat input at Title IV units, accounted for 32% of total abatement. The remaining reductions attributed to scrubbing are reductions in excess of the percentage reduction required of scrubbers under non-Title IV regulation, which is typically 70% to 90%. Switching to lower sulfur fuels occurred almost exclusively (99.9%) at coal-fired units and it consisted entirely of switching to lower sulfur coals. The remaining 0.1% of the emission reduction by switching occurred at oil-fired units, which were switched either to lower sulfur petroleum products or to natural gas. No coal units have been switched to natural gas because the price of natural gas is too high to justify abatement by this means.

First Year Effect

One of the most interesting phenomena of both Phase I and Phase II is that the largest reduction of emissions was made in the first year that units were subject to Title IV, which is to say, the first year in which they were required to pay a price for every ton of SO_2 emissions. Figures 2 and 3 show this effect for the 374 Phase I units that first

[6] 27 of these units were installed at the beginning of Phase I. Since 1998, when allowance prices first exceeded $200/ton, at least eight new retrofit scrubbers have been announced and three of these were on-line in 2001.

became subject to Title IV in 1995 (by law or through opting-in voluntarily) and have been so continuously since then and the Phase II units that became subject to Title IV in 2000.

Figure 2. Phase I unit emissions, allowances and counterfactual emissions

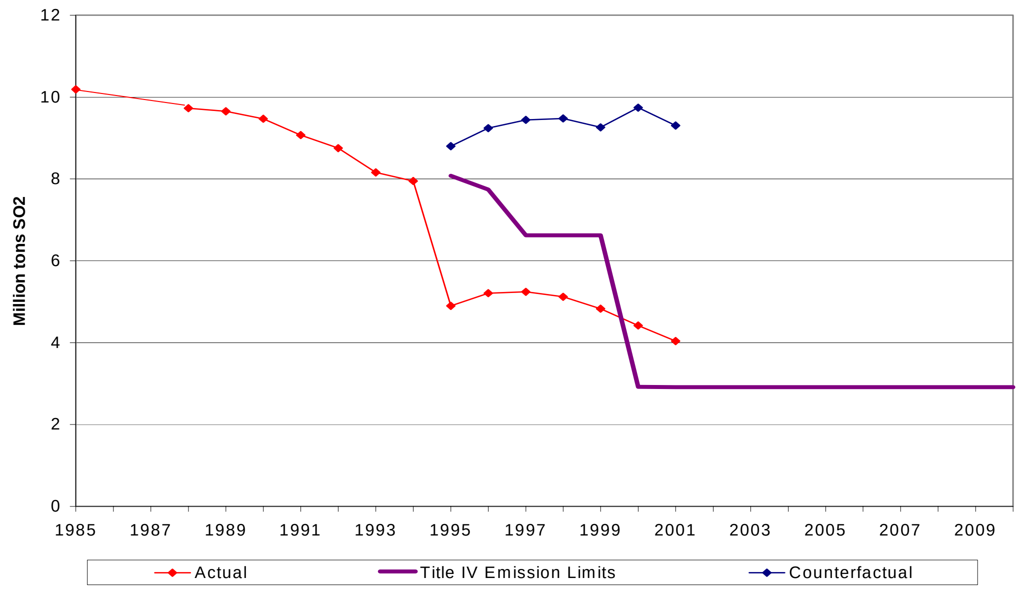
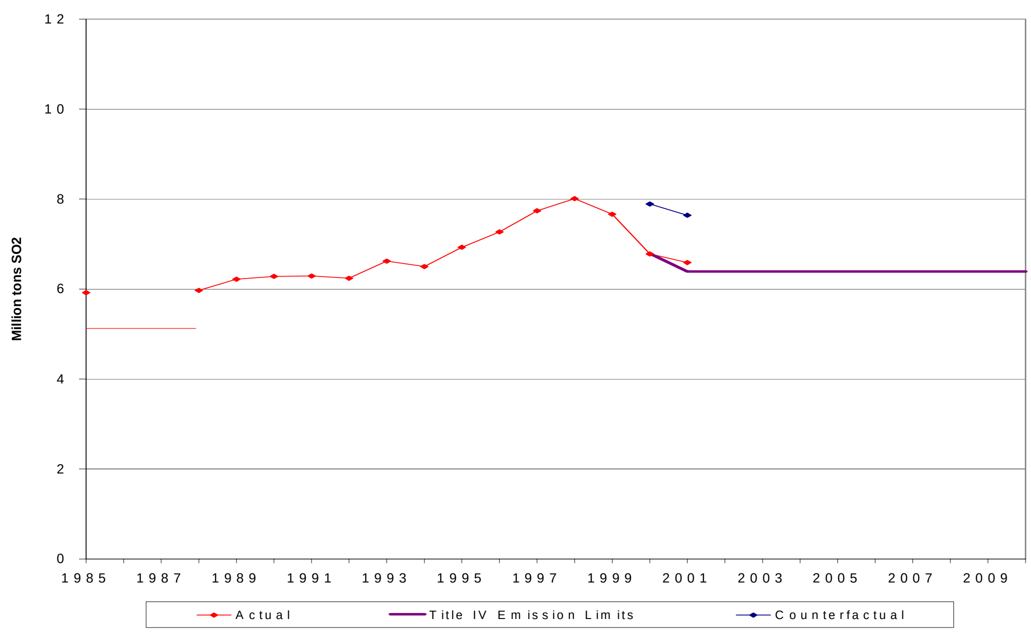


Figure 3. Phase II unit emissions, allowances, and counterfactual emissions



In both of these figures, the red line beginning in 1985 and continuing through 2001 depicts the evolution of actual SO_2 emissions; the lines beginning in 1995 in Figure 2 and in 2000 in Figure 3 and continuing to the right-hand side of each figure represents the total number of allowances issued to these units for each year; and the shorter line consisting of seven points in Figure 2 and two points in Figure 3 provides an estimate of counterfactual emissions, what emissions would have been for these units if Title IV had not been in force. The notable feature for each subset of generating units is the large reduction in emissions that is observed in the first year that Title IV took effect.

This first-year effect is particularly striking for the Phase I units. A steady decline in the trend of emissions can be observed in the late 1980s and early 1990s, but the reduction from 1994 to 1995 was much greater than any year-to-year decline observed before.[7] Title IV occasioned this sharp one-year decline; there simply is no other explanation. It is the more remarkable in that it can be seen as completely voluntary, at least with respect to the timing of the emission reduction since the total number of allowances issued for 1995 was in fact not very constraining.

The first-year effect is not as large in absolute or percentage terms for the Phase II units because these relatively low emission units contribute less to the aggregate emissions, but it is still noticeable. The start of Phase II broke what had been a steady upward trend in SO_2 emissions for these units that contrasts with the pre-Title IV trend for the Phase I units. In 2000, aggregate emissions for Phase II units were virtually the same as the number of allowances issued to these units, but the pattern beneath the aggregate is highly variable. Approximately 60% of the Phase II units receive more allowances than needed to cover calculate counterfactual (and generally actual) emissions; the surplus is effectively transferred to other Phase II units, generally located east of the Mississippi, that received fewer allowances than those unit's pre-Title IV and estimated 2000 counterfactual, emissions.[8]

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[7] Ellerman and Montero (1998) the declining trend in SO_2 emission prior to the onset of Phase I to the deregulation of railroads which made low sulfur western coal cheap in the Midwest. The appendix by Schennach in Ellerman et al. (2000) provides an econometric estimate that separates the amount of pre-1995 decline due to railroad deregulation and to anticipation of Title IV.

[8] Counterfactual emissions are calculated as the product of the observed, pre-Title IV emission rate and actual heat input for the year in question. For instance, 2000 counterfactual emissions for any given unit is

BANKING

One of the prominent features of Phase I was the accumulation of a bank of allowances that totaled 11.65 million tons at the end of 1999. Although most observers believed that these allowances would be used during the first decade of Phase II, it was never clear whether the amount of banking in Phase I was the result of reasonably rational banking programs implemented by the owners of Phase I affected units, which is to say, whether the level of banking was economically justified..

The effect of Phase II on Phase I unit emissions

One important sign that the owners of Phase I affected units have been engaging in reasonably rational banking behavior is provided by the change in total emissions from these units between 1999 and 2000, when the allocation of allowances for these units was reduced by about 50%. Economic agents who engage in reasonably efficient banking programs would ignore year-to-year changes in the number of allowances allocated and abate according to a banking program based on the cumulative required emission reduction over the relevant economic horizon—essentially smoothing abatement over time.

Figure 2 shows that the 56% reduction in allowances from 1999 to 2000 had little effect on emissions, which declined by 8% between the two years. The only change from 1999 to 2000 was the change in the banking position of these units; in 1999 they continued to bank allowances and in 2000 they started to draw down the accumulated Phase I bank.. The general shape in the trajectory of emissions, and in the net changes to the bank, is what would be predicted by economic theory when agents are able to redistribute emissions over time in a cost-minimizing fashion and they are faced with a sharp discontinuity in the temporal allocation of allowances (Schennach, 2000).

Optimality of Banking

The smooth path of aggregate emissions from Phase I units and the concomitant start of the draw down of the accumulated allowance bank does not imply that banking

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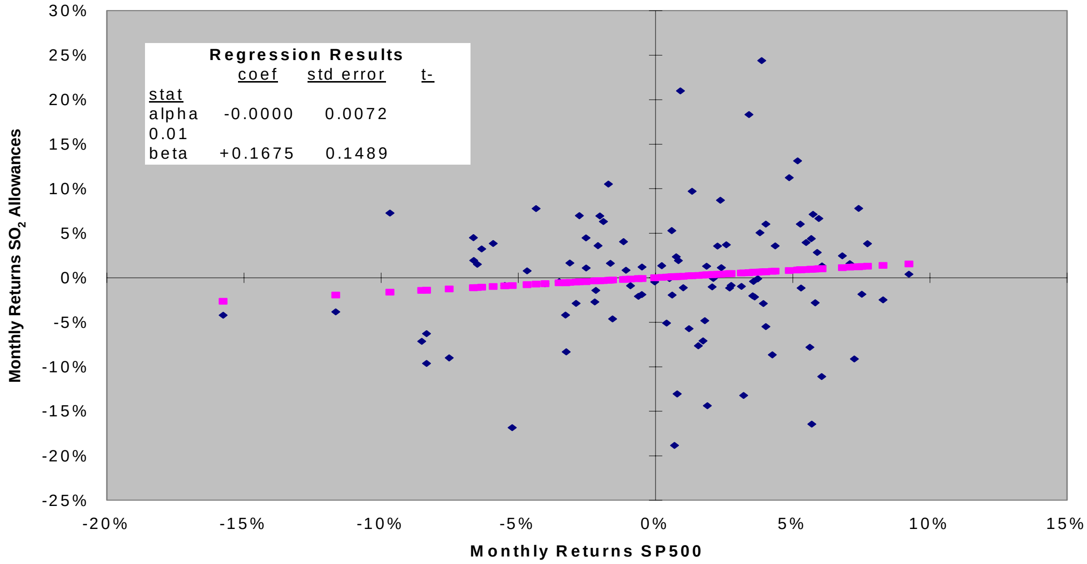
the product of that unit's 1998 emission rate and its 2000 heat input. Aggregate counterfactual emissions for any year is calculated by summing all the individual units.

behavior has been optimal, although it does eliminate the possibility of irrational hoarding, a common concern in the early days of Title IV. Any judgment on temporal efficiency requires that an appropriate discount rate be chosen, which is a non-trivial task.

The usual assumption has been that the owners of electric utilities would use an internal discount rate reflecting their weighted cost of capital; yet, finance theory is clear that the cash flows associated with certain projects or assets should be discounted by a rate reflecting the degree of undiversifiable risk, that is, the extent to which the returns from a particular type of asset vary with the returns from a well diversified portfolio of equities, such as the S&P 500. By the Capital Asset Pricing Model, the appropriate discount rate is the sum of the risk-free rate, associated with Treasury bills or notes, and a risk premium that depends on the asset's "beta," which is the slope of the line regressing the returns from the particular type of asset on the returns from a well-diversified portfolio of equities over a succession of periods. The empirically observed additional return associated with a well-diversified portfolio of equities (in comparison with T-bills for instance) is known as the equity premium for the undiversifiable risk of such a portfolio. The appropriate discount rate for any specific asset, such as SO_2 allowances, is then the risk-free rate plus the product of the asset's beta and the market equity premium. For example, a beta of 1.0 implies that on average the percentage returns from the specific asset (defined as the change in price of the asset plus any dividend payment) are the same as the general equity market; and lower or higher betas imply a lower or higher discount rate for the cash flows associated with the specific asset.

The capital asset pricing model is useful because it provides a means for determining the appropriate discount rate for any asset that is priced in some market. SO_2 allowances are financial assets whose ultimate value depends on the abatement costs avoided by their use for covering emissions in some period. They are also bought and sold in what appears to be a reasonably efficient market so that the returns from holding SO_2 allowances can be easily calculated and compared to those from holding a well-diversified portfolio of equities. Such a comparison is made in Figure 4 for the period from October 1994 through March 2003.

Figure 4. Returns from holding SO2 Allowances and the S&P500



The straight, slightly upward sloping line is the regression line, and its slope indicates the beta, which is statistically insignificantly different from zero. This result indicates that no correlation exists between the monthly returns from SO_2 allowances and the S&P500.[9] When the return from holding a diversified portfolio for some period is positive, the return from holding an SO_2 allowance in the same period is as likely to be negative as it is to be positive. Equivalently, SO_2 allowances constitute a zero-beta asset and this result implies that the appropriate discount rate for SO_2 allowances is the risk-free rate.[10]

It would take this paper to far afield to delve into the construction of an appropriate discount rate for SO_2 allowances, such as how to determine the risk-free rate and over what period of time; however, the result of that analysis, as developed more fully in Ellerman and Montero (2002), is given in Figure 5.

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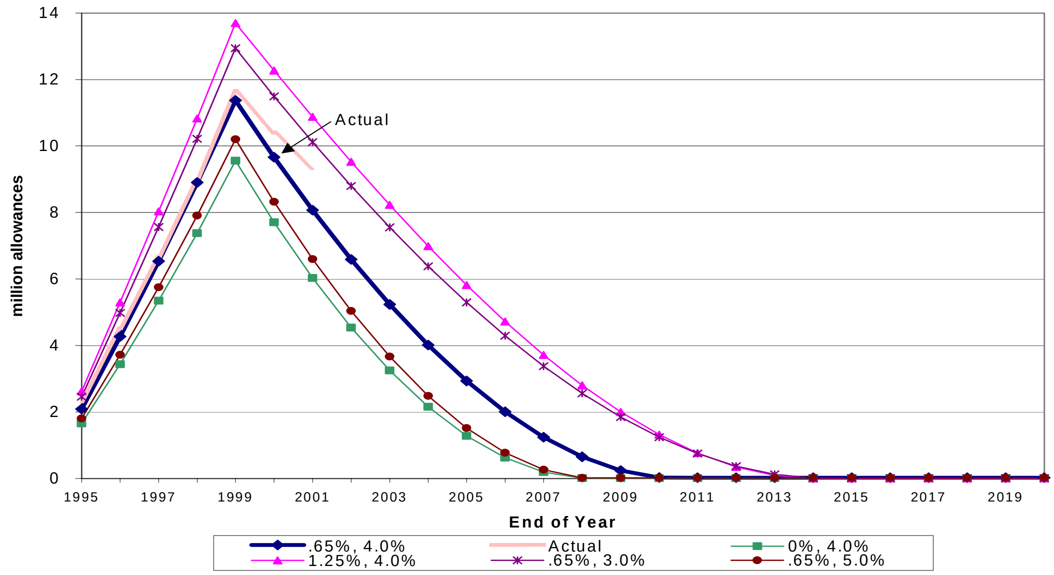
[9] Regressions on different market indices, for differing periods of time, and with corrections for serial correlation give similar results.

[10] It must be emphasized that the risk that is measured is systemic or undiversifiable risk, not asset specific risk. The latter can be reduced and avoided by constructing a portfolio with an appropriate weighting of assets whose returns are negatively correlated with the specific risk being diversified.

Figure 5. Simulation of optimal Title IV banking



The five peaked lines extending from 1995 through varying years in Phase II represent optimal aggregate bank holdings depending on plausible assumptions concerning discount rates and the expected growth of SO_2 emissions over the banking period. The fuzzy line that runs through 2001 represents actual aggregate bank holdings and it closely tracks the optimal path for a real discount rate of 4.0% and an expected growth of emissions of 0.65%. These are in fact reasonable assumptions for the real risk-free discount rate from the mid-1990s through 2001 and for pre-1995 expectations of expected SO_2 emissions growth without Title IV. However, the important point is not that the actual path tracks this particular line, but that it falls within the paths described by alternative plausible assumptions concerning real risk-free discount rates—3.0% and 5.0%—and for the growth of counterfactual emissions—0% and 1.25% per annum. The real risk-free discount rate varies over time, as do expectations of expected growth in counterfactual emissions, but these bounds fairly describe the variation in these parameters since Title IV began.

It would be too much to claim that banking has been optimal in any exact sense, but the lines in Figure 5 describe the range of reasonably efficient banking programs given reasonable assumptions about the most important parameters determining banking behavior. The envelope described by these banking programs would predict an end-of-Phase I bank of between 9.5 million tons and 13.5 million tons and the complete draw down of the bank sometime between 2008 and 2013. This envelope is consistent with what has been observed and what is expected, assuming no changes to Title IV during the remainder of the banking period. In summary, the response to the banking provisions of Title IV provides further evidence economic agents respond in a rational, cost-minimizing way when market-based incentives are made available.

NEW UNITS

A frequently maligned feature of Title IV is the endowment of allowances to incumbents (as of 1985-87) without any provision for allowances to new entrants. This feature is often decried as a barrier to entry for new generating units, an issue of particular concern when wholesale power markets are deregulated. This feature of Title IV could not be observed in Phase I, since existing plants only were included. However, any new fossil-fuel-fired generating unit of more than 25 MW^e that has come on line since enactment of the legislation in 1990 would be covered in Phase II, so that this effect can now be observed.[11]

One way to evaluate the effect on new units is to observe the frequency of generating units that were not allocated allowances. Zero-allowance units are not necessarily new units since re-activated, mothballed units not operating in 1985-87 would also not receive allowances, and there were some of these. Nevertheless, all new units would be zero-allowance units and the crux of the argument about barriers to entry concerns the absence of an allowance allocation. Of the nearly 3,000 units subject to reconciliation and emitting some SO_2 during 2000-2001, 981 are zero-allowance units, almost a third. This large number reflects mostly the increase in new gas-fired capacity that has been observed in 2000 and 2001.

Table 3 provides an accounting of these zero-allowance units by the time when they first appeared as generating units. In this presentation, a division is made between

[11] A few units that were in the planning stage in 1990 received contingent allowance allocations in the Title IV legislation. In the following analysis, three of these units that were operating in 2000 and 2001 have been excluded.

Phase II units that make a significant contribution to heat input or emissions (1420 units), which have been cited above, and the remaining units (1200) with small contributions to aggregate heat input (1-2% of the total) and emissions (≈ 0.2%). Since many of the new units were used for peaking purposes only or were only starting up as combined cycles in 2001, any assessment of the role of zero-allocation units must include these "remaining" or "insignificant" Phase II units.

Table 3. Zero-allowance Phase II units, by time of first generation

	Significant Units	Remaining Units	Total Phase II
Online prior to 2000	109	264	373
New in 2000	34	189	123
New in 2001	31	354	385
Total	174	807	981

Nearly all of the zero-allowance units are new, gas-fired peaking or combined cycle units that emit little SO_2, but a small number are not. In 2001, 61 units had an average emission rate higher than 0.05 lbs/SO_2 per mmBtu, which implies they were burning a petroleum product or coal; and 20 emitted more than 100 tons of SO_2 during the year. These small numbers might be used to argue that the absence of an allowance endowment discouraged new coal or oil capacity, but it is more likely that the compelling economics of gas-fired peaking and combined cycle generation (at least before the recent and persistent higher price levels for natural gas) explain this phenomenon. At the very least, it is evident that the lack of an allowance endowment does not impede the entry of new low-emitting generation capacity.

Quite apart from the issue of barriers to entry, the new gas-fired units have had a significant effect on SO_2 emissions. The year 2001 was the first year since 1992 in which the heat input into fossil fuel fired generating units declined thereby breaking what had been an eight-year succession of rising demand for fossil-fuels for the generation of electricity. The 3.2% decline in heat input from 2000 to 2001was the more remarkable in that fossil fuel fired generation of electricity in these two years was approximately constant. The explanation lies in the significant increment of new gas-fired combined cycle generating capacity that came on line in 2001.

The differing trends in fossil-fuel fired generation and fossil-fuel heat input due to the new combined cycle units emerges clearly from the latest EIA data, as shown in Table 4.

Table 4: Generation and Heat Input at Fossil-fuel fired Generating Units, 1999-2001

	1999	% Chg	2000	% Chg	2001
Generation (000 Gwh)	2,578	+4.31%	2,689	+0.07%	2,691
Coal	1,884	+4.46%	1,968	-2.79%	1,913
Oil/Gas	694	+3.89%	721	+7.90%	778
Heat Input (Quads)	23.45	+2.22%	23.97	-3.46%	23.14
Coal	19.33	+3.93%	20.09	-2.59%	19.57
Oil/Gas	4.12	-5.83%	3.88	-7.99%	3.57
Implied Efficiency					
All Units		+2.04%		+3.66%	
Coal Units		+0.51%		-0.21%	
Oil/Gas Units		+10.32%		+17.27%	

Source: EIA, Monthly Energy Review, February 2003

The effect of the new combined cycle units can be seen in the statistics for implied efficiency, which is the change of generation divided by the change in heat input. For instance, in comparing 2001 with 2000, fossil-fuel fired generation increased by less than .1% and heat input declined by 3.5%, which implies an improvement in efficiency of 3.66%. As can be seen from the decomposition by fuel, all of this comes from the oil/gas fired units. The efficiency of the coal units has been relatively constant in the aggregate, but the oil/gas generating units have improved in aggregate efficiency by about 10% in 2000 and 17% in 2001. The result in 2001, when demand for electricity was flat, has been a backing out of the coal units (-2.8%) and an increase in oil/gas generation (+7.9%). The improvement in efficiency also implies less demand for natural gas for generating electricity, a trend that is clearly evident in the EIA statistics (-8.0% from 2000 to 2001).[12]

The effect of the new gas-fired combined cycle generating units can be readily observed when the annual changes in emissions at generating units are decomposed into changes in emission rates at individual units, caused by fuel switching, and changes in heat input at those units. Table 5 provides an accounting of the changes in SO_2 emissions from 1999 to 2000 and from 2000 to 2001 by summing the observed changes at all affected generating units.

Table 5. Changes in SO_2 emissions by fuel and cause

000 tons SO_2	All Units	Coal Units	Oil/Gas Units
1999-2000 Changes	**- 1,254**	**- 1,132**	**- 122**
Emission Rate Changes	- 1,392	- 1,382	- 10
Heat Input Changes	+ 138	+ 250	- 109
2000-2001 Changes	**- 567**	**- 649**	**+ 83**
Emission Rate Changes	- 64	- 135	+ 71
Heat Input Changes	- 503	- 514	+ 12

Source: Derived from EPA CEMS data

The source of SO_2 reductions changes dramatically from the comparison of 1999 with 2000 and 2000 with 2001. All of the reduction in emissions from 1999 to 2000 can be attributed to an average lowering of emission rates at affected units, mostly by switching to lower sulfur fuels. This change is the first-year effect that has been discussed earlier: the downward shift in emission rates that occurs when units are first required to pay a price for all emissions. In contrast, nearly all of the reduction from 2000 to 2001 is due to lower heat input at affected units, which reflects the influx of new combined cycle

[12] The heat input data from the CEMS (Continuous Emissions Monitoring System) data collected by EPA confirms the general trend but not the magnitudes of improved generation efficiency for oil/gas units. For instance the CEMS data show oil/gas unit heat input to have increased by 2.7% from 2000 to 2001, instead of declining by 8.0%, as the EIA data indicate. A 2.7% increase in heat input would still imply some improvement in efficiency, given the increase in gas-fired generation, but not 17%. There are obvious problems of comparability concerning oil and gas units. While the EIA and EPA statistics agree closely with respect to heat input into coal-fired units, the disagreement for oil/gas fired units is large. EIA reports 3.57 quads of oil and gas heat input in 2001, while the EPA CEMS indicates 4.85 quads of oil and gas heat input, or 36% more.

capacity and the resultant backing out of coal-fired and single cycle oil and gas-fired generation. Had the new combined cycle units not been brought on line, the demand for electricity would have been met by existing generating capacity and SO_2 emissions would have been about 500,000 tons, or about 5%, higher than they were.

COST

No estimates of the actual cost of compliance with Title IV in Phase II have been made; however, two groups of analysts made ex post estimates of the cost of compliance in Phase I and both provided updated estimates of the expected cost in Phase II based on observed Phase I cost. These estimates of Phase II cost can be now be assessed based on the observed abatement in Phase II and allowance price behavior. The two ex-post evaluations of Phase I compliance cost were made by Carlson et al. (2000) and Ellerman et al. (2000) [hereafter, CBCP for the initials of the authors of Carlson et al. and MCA for *Markets for Clean Air*, the title of the book published by Ellerman et al.]

CBCP and MCA agree roughly on the cost of compliance in the early years of the Acid Rain Program. The latter estimates the cost of compliance at $726 million in 1995 and about $750 million in 1996, while the former places the cost at $832 million in 1995 and $910 million in 1996, all stated in 1995 dollars. These estimates are not as far apart as they would seem. Complete comparability is not possible because of differences in methodology; however, both treat scrubber expense in the same manner.[13] Although they largely agree on the fixed cost of scrubbers ($375 million in MCA and $382 million in CBCP), they differ significantly on the variable costs associated with scrubbers ($89 in MCA million and $274 million in CBCP).[14] CBCP uses scrubber data that reflect pre-1995 estimates of the variable cost of scrubbing, but the actual performance of the Phase I scrubbers has been much better than predicted. Correction of this item alone largely

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[13] MCA provides a bottom-up, plant-by-plant analysis based on reported capital costs and observed sulfur premia. CBCP conducts an econometric estimation of a translog cost function and share equations of unit-level data for 734 *non-scrubbed* units over the 1985-94 period and then takes the resulting parameter values to form marginal abatement cost functions for individual units, which are then used to estimate actual costs based on observed 1995-96 emission levels. Scrubbed units are handled separately on a cost accounting basis using identical cost of capital and depreciation assumptions as in Ellerman *et al.* (2000).

[14] The numbers cited from CBCP are from their break-out of the costs of 2010 compliance. This estimate will be approximately the same as the scrubber costs in 1995-96 since the fixed costs are annualized over 20 years, fuel costs are assumed not to change after 1995, the number of scrubbers is assumed to remain unchanged, and costs are stated in 1995 dollars.

removes the disparity in cost estimates between these two ex post evaluations. As an approximate figure, $750 million is probably a reasonable estimate of the annual cost of abatement in the first years of Phase I.

A simple estimate of Phase II cost can be obtained by extrapolation of this estimate using the increase in the amount abatement observed and the behavior of allowance prices, which can be taken as a reasonable indication of short and long-run costs of abatement. The estimate of $750 million for early Phase I costs corresponds to about 4.0 million tons of abatement, while currently observed abatement is about 6.5 million tons, or 63% more. Although three new retrofitted scrubbers were operating as of 2001, most of the 2.5 million tons of additional abatement since 1995 has occurred through switching to lower sulfur coal. Allowance prices provide a good proxy for the per ton cost of this additional abatement since there is every indication that utilities recognize that allowances are perfect substitutes for abatement at the margin and act accordingly.

After an initial downward adjustment, allowance prices have moved generally upward, as would be predicted for agents engaged in reasonably rational banking programs; and since early 1998, prices have ranged from highs of about $210 to lows of about $130. In addition, the significant observed reduction in scrubber cost has brought the total costs of scrubbing within the upper end of the range of allowance prices since 1998.[15] Hence, it is reasonable to assume that the increment total cost of the additional abatement observed since 1995-96 lies between $150 and $200 a ton. This implies an additional total cost of abatement between $375 million and $500 million (2.5 million tons of additional abatement times $150/ton and $200/ton, respectively) and a total estimated cost for early Phase II abatement of between $1.125 billion and $1.25 billion. Since another 1.5 million tons is to be abated as the Phase I allowance bank is drawn down, total annual costs for compliance with the completely phased-in Phase II limits would be about $1.5 billion assuming an incremental per ton cost of $200.

[15] Ellerman and Joskow (forthcoming) provide a discussion of the evolution of estimates of scrubbing costs and estimates of the cost of scrubbing the remaining unscrubbed coal units. Taylor et al. (2001) also provide estimates of the decline in scrubber costs since the early 1970s.

By any reckoning, these estimated costs, made with the benefit of observed data and trends, are lower than the ex ante predictions when Title IV was enacted. Most of the often noted disparity between ex ante and ex post estimates of the cost of the Acid Rain Program reflects very different assumptions about the nature of proposed acid rain controls, the projected demand for electricity, and the relative availability and cost of low sulfur coal. For instance, the total annual costs associated with some of the early proposals to control acid rain precursor emissions were estimated at amounts ranging from $3.5 to $7.5 billion, 2 to 5 times what now appear likely to be the cost of a fully phased-in program. Although the details of these earlier proposals varied, they generally mandated scrubbers at a significant number of units and allowed very limited emissions trading. Once the proposal that ultimately became Title IV was proposed (in 1989) and enacted (in 1990), the ex ante cost estimates for the fully phased-in program with trading fell to a range from $2.3 billion to $6.0 billion, with most of this variation reflecting varying assumptions about the extent to which emissions trading would be used.

A good example is provided by the discussion in MCA (pp. 231-235) of the few ex ante estimates of Phase I costs and a comparison with the MCA estimate of actual cost. Most of the variation in the ex ante estimates, made only a few years before Phase I began, reflects differing assumptions about the extent to which utilities made full use of the flexibility afforded by emissions trading. When compared on an average cost basis to account for differences in assumptions about the quantity of abatement (due to differing assumptions about the growth in electricity demand and the extent of banking), MCA's ex post estimate of cost in 1995 was slightly above (3-15%) ex ante estimates assuming full use of emissions trading and 20-35% below estimates that assumed relatively little use of emissions trading.

CBCP provides a very helpful quantification of the causes of the change between the early estimates of fully phased-in Title IV costs and the current estimates. In analyzing the causes for the change between expected costs as of the mid-1980s and actual costs in early Phase I, CBCP find that the marginal cost of abatement for a representative generating unit has been approximately halved and that 80% of the reduction in cost is attributable to falling price of low-sulfur coal relative to the price of high sulfur coal and that the remaining 20% is attributable to technological change. Estimates of fully phased-in Phase II costs are then made using different assumptions about coal prices, technological change, and the use of trading, as illustrated in Table 6.

Table 6: Simulated Total Cost of Compliance with Title IV in 2010
(billion 1995 dollars)

Cost Assumptions	Command-and-Control	Efficient Trading
1989 Prices and Technology	$2.67	$1.90
1995 Prices and Technology	$2.23	$1.51
1995 Prices and 2010 Technology	$1.82	$1.04
Source: Carlson et al. (2000), Table 2, p. 1313		

Since efficient trading is being observed, the relevant estimate for Phase II cost from this study lies between $1.04 billion and $1.51 billion, depending upon the amount of technological progress from 1995 to 2010. The estimate of $1.5 billion presented above lies at the upper end of this range, but it does not attempt to estimate further improvements in abatement technology. Even so, this table shows that, while costs depend on prices and technology, which are not subject to program design, the ability to trade, which is subject to program design, can lead to equally and even more significant reductions in the cost of compliance.

In summary, it seems clear that Phase II costs are considerably lower than what was expected and that this difference is attributable to 1) the flexibility allowed by Title IV, 2) improvements in abatement technology, especially in scrubbers, and 3) the lower prices for low sulfur coal due largely to changes independent of Title IV. As detailed in Ellerman and Montero (1998), the most important independent change was the reduction in rail rates that made low sulfur bituminous coals from the West economically attractive as a replacement for high sulfur, Midwestern bituminous coal and significantly reduced the abatement requirements imposed by the Title IV cap.

CONCLUSION

With two years of Phase II compliance data now available (and a third year's data about to be released), more confident answers concerning the effectiveness of cap-and-trade systems can be made. Although not discussed in this paper, nothing suggests that allowance markets are working less efficiently in Phase II than in Phase I; and there is plenty of anecdotal evidence to suggest that the owners of Title IV affected units are avoiding whatever less than optimal abatement choices may have been made in Phase I. The more important evidence arising from Phase II compliance concerns the distribution of total abatement, the efficiency of banking, the extent to which lack of an allowance endowment impedes the entry of new generating units, and not least the total cost of compliance. This evidence provides the basis for the following tentative conclusions.

1. By far, the bulk of the abatement by Title IV affected units is being made by the Phase I units that, by definition, are the larger units with relatively high pre-Title IV emission levels, located mostly in the Midwest. About three-quarters of the reduction in SO_2 emissions due to Title IV is occurring in this region of the country and this share is larger that that region's share of electricity generation or pre-Title IV emissions. This pattern of abatement implies that the cheapest abatement lies where emissions are greatest and that market-based incentives can be expected to direct abatement to these locations.

2. The amount of banking undertaken in Phase I and the rate of draw down in Phase II has been reasonably efficient. The observed response to the sharp discontinuity in marginal cost created by the two phases of Title IV suggests that, when banking is allowed, agents take a longer view and distribute abatement efficiently over time. This behavior also implies a non-mandated acceleration in the timing of the required cumulative abatement that is environmentally beneficial.

3. There is little evidence in Phase II that failing to endow new generating capacity with allowances impedes entry. While a frequently voiced complaint, and perhaps unfair in some non-economic sense, the practical realities are that neither short-run nor long-run marginal calculations concerning production or entry are affected by the allowance endowments in Title IV. Moreover, SO_2 allowance cost

is a relatively minor consideration when compared with permitting and siting costs and new source performance requirements.

4. While detailed studies of Phase II compliance cost have not been performed, reasonable extrapolations from carefully done earlier analyses of Phase I cost continue to indicate that the fully phased in cost of Title IV is and will be significantly lower than expected, somewhere between $1.0 billion, at the very lowest, and perhaps $1.5 billion at the high end. Much of the explanation for the disparity with the much higher ex ante forecasts lies in differing assumptions about the rate of improvement in abatement technology and other changes in the coal sector that are largely independent of Title IV; however, a significant share of the disparity can be attributed to the flexibility provided by Title IV and electric utilities' willingness to take advantage of the cost-saving opportunities provided by emissions trading.

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