BACKGROUNDER

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The U.S. Environmental Protection Agency's Acid Rain Program

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RESOURCES FOR THE FUTURE

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I. Introduction

Congress established the world's first cap-and-trade system by creating the Acid Rain Program (ARP) during its 1990 amendments to the Clean Air Act. The purpose of the ARP was to reduce acid rain deposition by decreasing sulfur dioxide (SO_2) emissions from power plants to 50 percent below 1980 levels by 2010. To achieve this goal, regulators capped the annual aggregate SO_2 emissions from central and midwestern power plants and created an allowance trading market.

The ARP is largely considered a successful cap-and-trade system. By 2007, the program had achieved its 2010 reduction goal at an estimated cost that was considerably lower than that of *command-and-control* regulations, which mandate that each power plant adopt a specific technology to reduce SO_2 emissions or a standard that requires each power plant to emit below a specific fraction of SO_2 emissions per unit energy produced (Carlson et al. 2000).[1] The success of the ARP informed the architecture of other programs, including the world's largest cap-and-trade program: the E.U. Emissions Trading System (Convery 2008).

This backgrounder describes the SO_2 allowance market of the ARP, reviews the ARP's effectiveness, discusses the monitoring systems of the ARP, summarizes publicly available ARP data sets, and highlights limitations of the ARP.

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This backgrounder is one in a series prepared for the project "Planning for the Ex Post Analysis of U.S. Climate Policy" to inform discussions and assessments of U.S. climate policy. The backgrounders summarize research on the following topics: (i) competitiveness impacts of climate policy; (ii) climate policy, international trade, and emissions leakage; (iii) Kyoto flexibility mechanisms: the Clean Development Mechanism and joint implementation; (iv) land use, land-use change, and forestry; (v) EU Emissions Trading System, and (vi) the U.S. Environmental Protection Agency's Acid Rain Program. Taken together, these backgrounders summarize research on several key aspects of climate policy. In addition to helping inform discussions and assessments of climate policy, the backgrounders are intended to provide informative overviews of each topic to anybody interested in conducting or better understanding climate policy assessment, including researchers, students, and experts in academia, government, nongovernmental organizations, and industry. Funding for this project has been provided by the Alfred P. Sloan Foundation.

[1] U.S. Environmental Protection Agency, Acid Rain Program 2007 Progress Report: http://www.epa.gov/airmarkets/progress/arp07.html.

II. An Overview of the Sulfur Dioxide Trading Market

This section explains the theory behind, and the implementation of, the SO_2 trading market under the ARP.

A. Cap-and-Trade Framework

The ARP set an overall cap on SO_2 emissions by allocating a fixed number of tradable allowances to each regulated power plant. At the end of each year, plants had to surrender one allowance for each ton of SO_2 emitted. Plants could buy, sell, or save allowances for future use—also known as banking. However, plants could not borrow allowances from the future. This type of policy is known as cap-and-trade.

This market-based trading system facilitated low-cost SO_2 reductions via two pathways: flexibility and trade. Regarding flexibility, the U.S. Environmental Protection Agency (EPA) dictated annual emissions targets, not how they were achieved; this gave plants the flexibility to search for the most cost-effective SO_2 reductions. Regarding trade, the ARP allowed plants to benefit from heterogeneity in abatement costs. For example, plants with low abatement costs could sell unneeded allowances to firms with higher abatement costs for a profit. Both firms benefited from this transaction: the plant with lower costs received additional profit, whereas the plant with higher costs reduced expenditures by postponing or avoiding costly emissions reductions. By implementing a cap-and-trade system—and therefore embracing flexibility and trade— the ARP was constructed to achieve the targeted level of emissions at least cost, at least on a theoretical level.

B. Implementation of the Acid Rain Program

The goal of the ARP was to reduce annual aggregate SO_2 emissions from power plants located in the central and northeastern United States to 8.95 million tons by 2010. This represents an annual decrease of 10 million tons compared to 1980 levels, or about 7 million tons below levels expected in 1990 for 2010. To achieve this goal, the ARP was introduced in two phases.

Initiated in 1995, Phase I covered 263 generating units at 110 large (capacity greater than 100 megawatts) power plants. During Phase I, regulators allocated allowances to power plants equal to an emissions rate of 2.5 pounds of SO_2 per million British thermal units (Btus) of heat input multiplied by the unit's average heat input for 1985–1987. However, this formula deviated in some important ways. In particular, regulators granted additional allowances to facilities that installed flue gas desulfurization equipment—for example, scrubbers—a provision intended to protect eastern high-sulfur coal production (Ellerman et al. 2000). Additionally, some Phase II

sources chose to comply early by voluntarily participating in Phase I. With these additions, Phase I ultimately regulated more than 400 units (Burns et al. 2011).

Initiated in 2000, Phase II extended coverage to nearly all coal-fired power plants with greater than 25 megawatts of capacity. Overall, Phase II covered more than 3,500 units. In Phase II, regulators allocated allowances according to a more stringent formula equal to the lesser of 1.2 pounds of SO_2 per million Btus, or a plant's 1985 recorded emissions rate multiplied by its average heat input for 1985–1987. Deviations to this formula allowed unique allocation rules for certain categories of plants, allocations based on special interests, and the allocation of bonus allowances (Ellerman et al. 2000). Each year, a small percentage of allowances were auctioned, and the proceeds were redistributed to existing sources on a pro rata basis (Ellerman et al. 2000).

III. Program Effectiveness

Economists widely regard the ARP as an environmental, regulatory, and economic success, but critics point to its flaw in being unable to respond to new information about costs and benefits. In 2007, the ARP surpassed its original environmental goal three years early: regulated power plants emitted only 7.6 million tons of SO_2 (Taylor 2012). By 2009, emissions had further declined to 5.7 million tons (EPA 2010). This trend of achieving targets ahead of time was caused by the introduction of the Clean Air Interstate Rule (CAIR), which heightened expectations of a more stringent SO_2 cap. Over the course of the entire program, regulated power plants achieved a nearly perfect compliance record—meaning that nearly all of these plants held enough allowances to cover SO_2 emissions (Burns et al. 2011). In addition, the actual costs of the ARP were lower than most ex ante estimates of this program and of other proposed programs to reduce SO_2 emissions. Moreover, estimated costs were very low compared to estimated benefits: Chestnut and Mills (2005) estimate that benefits—including improvements in human health and natural resources—outweighed costs by a factor of 40 to 1. That astonishing benefit-to-cost ratio suggests that, ex post, the level of the cap was set too high. Finally, actual costs to EPA to implement the ARP during its first five years were a modest $44 million.

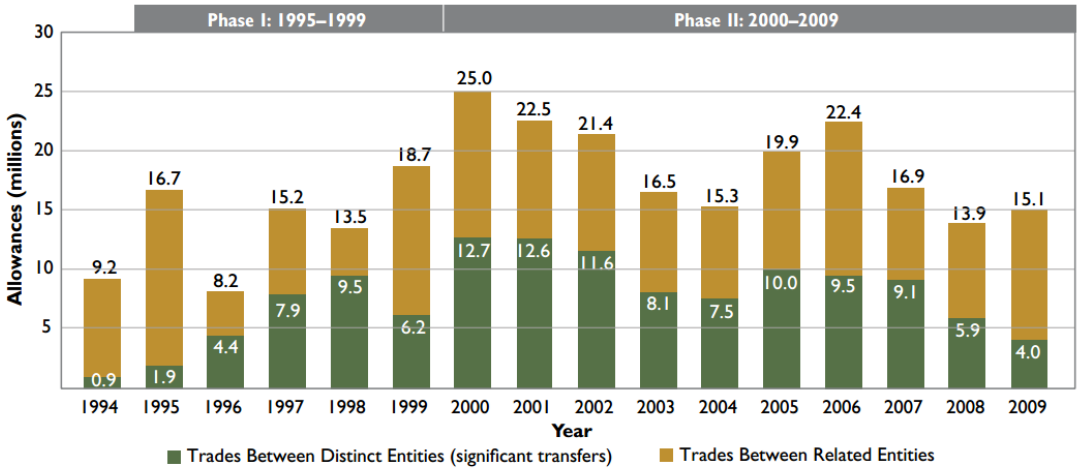
Before the ARP began, several studies had projected that cap and trade would reduce SO_2 emissions more cost-effectively than two leading command-and-control alternatives: mandating technologies (in this case, requiring every plant to install scrubbers that remove SO_2 from power plant emissions) or source-specific standards (requiring every plant to emit SO_2 at or below a certain rate per megawatt-hour). Experts projected that the cost of these policies would be $7.5–$11.5 billion and $3.4–$7.5 billion per year, respectively, whereas EPA estimated that the ARP would cost $1.9–$5.5 billion per year (Burtraw 1998, 1999).

Generally, the actual cost of the ARP has been lower than that estimated by studies. Moreover, Taylor (2012) shows that regulated power plants also overestimated allowance prices. Estimates of actual implementation costs are $1.17–$2 billion annually (Chestnut and Mills 2005; EPA 2011). Many factors are responsible for the low cost of SO_2 reductions under the ARP, including an efficient allowance market, banking of unused allowances, process and patentable innovations, and the availability of low-sulfur western coal. To varying degrees, these factors are attributable to the ARP and result in low SO_2 allowance prices; over most years of the program, prices were roughly one-quarter of the level expected initially.

A. Efficient Allowance Market

The ARP created an effective SO_2 allowance market. Albrecht et al. (2006, 1478) conclude that the SO_2 allowance market is "basically as efficient as financial markets." This market efficiency enabled regulated power plants to easily search for low-cost SO_2 reductions, as indicated by high volumes of trade between economically unrelated entities (Burtraw and Szambelan 2009, 2010). Figure 1 shows trade volumes between unrelated (distinct) and related entities.

Figure 1. Trade between Entities under the Acid Rain Program (1994–2009)



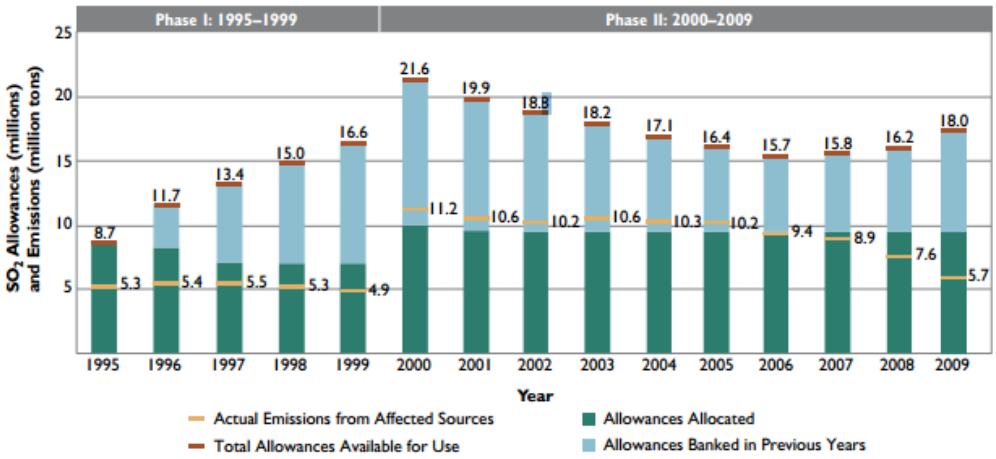
Source: Burns et al. (2011, Figure I-4).

B. Banking of Unused Allowances

Regulated power plants also heavily relied on banking allowances to reduce costs. In preparation for Phase II, regulated power plants essentially overachieved reductions in Phase I

and banked the associated unused allowances for Phase II (Ellerman et al. 2000). Figure 2 shows annual emissions and allowance banking by participating sources.

Figure 2. SO_2 Emissions from ARP Sources (1995–2009)



Source: Burns et al. (2011, Figure I-2)

C. Innovation

The replacement of command-and-control policies with the ARP changed the nature of innovation in SO_2 mitigation technologies in somewhat unexpected ways. Focusing on flue gas desulfurization technology (scrubbers), Popp (2003) finds that the number of patentable innovations dropped after the ARP was introduced; Taylor (2012) confirms this drop in patentable innovations for scrubbing technologies after the introduction of the ARP. Command-and-control policies, such as those embodied in performance standards for new coal plants, mandated that new power plants install a scrubber with a 90 percent SO_2 removal efficiency; but once this removal rate was achieved, there was no reward for further increasing removal rates (Burtraw and Szambelan 2009, 2010). These policies narrowly incentivized innovation that reduced costs. Although these innovations were patentable, the "research performed under [the command-and-control] policy regime did not improve the environmental effectiveness of scrubbers (Popp 2003, 658)." In contrast, the ARP incentivized process innovations that were not patentable but improved the SO_2 removal efficiency of scrubbers beyond 90 percent, with recent vintages achieving removal rates of 95 percent or more (Popp 2003). The ARP also allowed for other technological innovations, including fuel mixing. Before the ARP, engineers believed that blending more than 5 percent of low-sulfur coal into high-sulfur coal greatly impaired the performance of boilers. However, experimentation in response to the ARP demonstrated that higher levels of blending were possible (Burtraw and Szambelan 2009, 2010). Compared to

command-and-control policies, the ARP incentivized unpatentable processes that reduced costs and increased environmental effectiveness.

D. The Availability of Low-Sulfur Western Coal

The availability of low-sulfur western coal is perhaps the most frequently cited determinant of the low costs of SO_2 reductions. Although some believe that this new supply of coal would have occurred without the ARP, Burtraw (2000a,b) provides an alternative perspective. Railroad companies—which shipped this relatively cleaner coal—actually realigned their investment plans in response to the passage of the ARP to capture shares of the new market demand for low-sulfur coal induced by the ARP. Consequently, predicted bottlenecks that precluded eastern plants from using cleaner western coal failed to materialize. Compared to technology or performance standards, Burtraw (2000) contends that the ARP accelerated environmentally beneficial trends already occurring in the fuel markets.[2] Therefore, it seems likely that the ARP leveraged investments from the railroad industry that lowered SO_2 allowance prices.

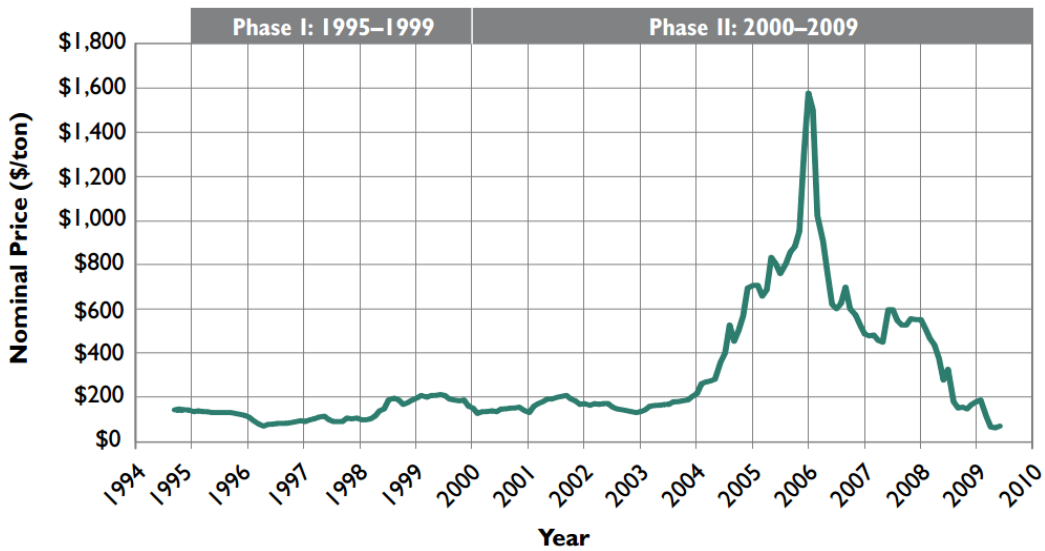
E. Historical Allowance Prices

Figure 3 shows historical prices of SO_2 allowances, which reflect the low cost of implementing the ARP. Early allowance prices ranged between $100 and $200, significantly lower than ex ante projections (Burns et al. 2011). Prices remained stable at this level throughout Phase I and into the early years of Phase II. In late 2003, EPA proposed CAIR which heightened expectations of a more stringent SO_2 cap and, therefore, increased allowance prices. As CAIR moved forward, allowance prices steadily increased up to around $800, spiking at $1,600 in December 2005. During this period, the ARP markets essentially became the new CAIR SO_2 market (EPA 2010). Protracted lawsuits ensued, tracked by a steady decline in allowance prices. In 2008, the courts vacated CAIR, and SO_2 allowance prices collapsed to all-time lows, although the court subsequently reinstated CAIR and left it in effect until EPA could develop an alternative. On July 6, 2011, EPA finalized the Cross-State Air Pollution Rule (CSAPR) to replace CAIR. This rule regulates SO_2 emissions from a total of 28 states and also regulates nitrogen oxides (NO_x). It introduces a new compliance instrument that can be traded; however, it

[2] Burtraw (2000) argues that a technology standard that mandated scrubbers would have precluded any advantage to using low-sulfur coal, rendering the additional cost of low-sulfur fuel unnecessary. Compared to a performance standard, Burtraw (2000) argues that plants would not have been incentivized to overcomply at facilities closer to clean western fuel sources.

limits the amount of interstate trading or allowance banking that can occur.[3] This regulation was also subsequently overturned by the courts; at the time of this writing, the decision is under appeal. Currently, the ARP market is in flux, with prices very low, essentially anticipating the CSAPR market.

Figure 3. Monthly SO_2 Allowance Price (1995–2009)



Source: Burns et al. (2011, Figure I-5).

IV. Monitoring Systems

Cap-and-trade systems require reliable methods for measuring emissions and tracking allowances to ensure accountability, transparency, and market functionality. Accurate monitoring of emissions data is necessary for guaranteeing that each allowance represents the same amount of emissions reduced, enforcing compliance, and measuring the environmental impact of the program. Similarly, tracking allowance trades provides essential information about market function, sending signals to utilities about market movement and informing regulators about market liquidity.

EPA enforces strict emissions monitoring requirements through continuous emissions monitoring protocols established under Title IV of the Clean Air Act. Affected sources are required to carefully maintain and report hourly emissions data in quarterly electronic reports.

[3] U.S. Environmental Protection Agency, Cross-State Air Pollution Rule: http://www.epa.gov/airtransport/.

EPA uses automated software audits to rigorously verify the completeness and integrity of data; this evaluation process was reengineered in 2009 under the Emissions Collection and Monitoring Plan System.[4] The ecological impacts of SO_2 reductions are measured separately by a network of monitoring programs that track air quality, wet deposition, dry deposition, and ecological conditions.

EPA also maintains complete records of all allowance transactions through the Allowance Management System (AMS).[5] Any interested party can buy or sell allowances, including utilities that hold allowances for compliance purposes, brokers hoping to profit from price increases, and environmentalists attempting to reduce emissions by retiring allowances. The AMS allows any account owner to track the number of allowances held within other accounts and to view the trading history of each individual allowance. Although allowance transactions take place in an independent spot market, any allowance that is bought or sold must eventually be registered in EPA's allowance tracking system to be used for compliance purposes.

V. Public Data Sets for the Acid Rain Program

The EPA Clean Air Markets Division makes all ARP data available for query or download through an interactive website titled Air Markets Program data.[6]At the most basic level, the site offers a "section with queriable graphs and tables of power plant level emissions, allowance and compliance data. Intermediate users may create data reports interactively through an easy-to-use data query system. Researchers and advanced users can also download raw data through a separate area of the website, or more directly through the agency's extensive Federal Test Procedure (FTP) site.[7] The Air Markets Programs data website also supports an interactive web-map that plots power plant locations, allowing users to display emissions information graphically and retrieve information about plants in specific locations.

The ARP reflects the principles of transparency and universal access to information. Clear plant and unit identifiers are provided for all data sets. Moreover, EPA provides access to detailed information on the operation of individual plants, including hourly operations data. EPA

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[4] U.S. Environmental Protection Agency, Emissions Collection and Monitoring Plant System: http://www.epa.gov/airmarkt/business/ecmps/index.html.

[5] U.S. Environmental Protection Agency, Acid Rain program SO_2 Allowances Fact Sheet: http://www.epa.gov/airmarkt/trading/factsheet.html.

[6] U.S. Environmental Protection Agency, Air Markets Program Data: http://ampd.epa.gov/ampd/QueryToolie.html.

[7] U.S. Environmental Protection Agency, FTP Directory: ftp://ftp.epa.gov/dmdnload/.

generally makes this and other types of ARP data publicly available and processes data sets in multiple user formats to facilitate public access. In addition, EPA provides access to annual reports that provide summary information and analyses concerning recent data trends.[8]

The data available on the website are divided into five core areas: allowances, emissions, compliance, air quality and deposition, and facility attributes and contacts. All categories offer complete data, extending across the entirety of the ARP program, and most are up to date, containing information from the most recent fiscal quarter. In general, most data are available at a highly disaggregated level with observations for each unit or hour of emissions. In many cases, alternative prepackaged data sets are also available at more aggregated levels. Depending on the size of data sets, some data are available in the form of a single annual spreadsheet, whereas other data are available for download only in smaller subsets—usually split by state or month. Table 1 summarizes the characteristics of each EPA data set.

Table 1. Summary of Data Sets for the Acid Rain Program

Type of data	Observation unit	Time unit	Data collection method	Identifies facility	Spreadsheet time scale	Frequency of data release	Timeliness of data release
Allowance trading	EGU	Daily	EPA allowance tracking system	Yes	Annual	Daily	Most current data available
Emissions	EGU	Hourly average	Continuous emissions monitoring	Yes	Monthly (by state)	Quarterly	Most current data available
Compliance	Facility (power plant)	Annual	No original data	Yes	Annual	Annual	Most current data available
Dry deposition	Monitoring station	Total weekly accumulation	Open-face dry filters	NA	Full program history	Weekly	Most current data available
Atmospheric concentration	Monitoring station	Hourly average	Gas analyzers	NA	Annual	Daily	Most current data available
Meteorology and ozone	Monitoring station	Hourly average	Various instruments	NA	Annual	Daily	Most current data available

Notes: EGU,Electricity Generating Unit.

[8] U.S. Environmental Protection Agency, Progress Reports:http://www.epa.gov/airmarkets/progress/progress-reports.html.

A. Allowance Data

The allowance category presents data related to market transactions through all of EPA's emissions trading programs, including the ARP (SO_2), but also the Budget Trading Program (NO_x) and CAIR (SO_2 and NO_x). The ARP has the largest historical data set, which is divided into annual spreadsheets dating back to 1994. Allowance transaction data for the current year are updated almost daily. Observations are at the individual account level, with each unit owning a separate account. Data fields related to plant identification include the account name, account owner, facility Office of Regulatory Information Systems Plant Location (ORISPL) number, and source category. Transaction information includes the date of the transaction (or confirmation), the number of allowances traded, and an identification of both the buyer and the seller. Descriptive information about allowances includes allowance serial numbers, allowance types, and allowance vintages. A final variable specifies the transaction type, distinguishing between *bookkeeping* transactions, which occur between units with common ownership, and *arm's-length* transactions between economically unrelated parties.

EPA does not maintain certain types of sensitive business data, such as the price associated with allowance transfers—instead, price signals are maintained privately through a market price index. Subsequently, the EPA allowance data set cannot be used to determine the compliance costs at a specific facility. Some utilities voluntarily disclose information about compliance costs to the Securities and Exchange Commission or to private stakeholders; however, there are wide inconsistencies in disclosure regarding the terms of transactions under the ARP (Freedman and Stagliano 2008).

A separate data set includes information about the initial allocation of allowances. These data are separated into two time periods: the first for 2000–2009 (pre-CAIR) and the second for after 2009 (post-CAIR). The data set shows annual allowance allocations to each electricity generator for each time period; the allocations vary based on different allocation formulas for the ARP and for CAIR. The data are broken down by total allocations into several different categories, depending on the legislative provision or allocation rule used to distribute each group of allowances. The majority of allocations are in the form of basic allowances. However, smaller distributions qualify as bonus allowances and as withholdings for several uses, including auctioning, repowering, and conservation.

B. Emissions Data

Utility companies provide hourly emissions data to EPA for each unit on a quarterly basis. In turn, EPA updates current emissions data on a quarterly basis with only a small lag time between data collection and dissemination. Emissions data are collected hourly at the unit level,

creating a large data set with an essentially continuous time scale. Because of the large size of the emissions database, prepackaged data sets of hourly emissions are broken down by state for each month of the year. The basic identification data include unit and facility identifiers, date and hour identifiers, and unit operation during each hour. Data also include measured hourly emissions levels of SO_2, NO_x, and carbon dioxide; calculations of pollution emissions rates; and hourly heat input.

Emissions data are also available at different levels of aggregation as well as in different data formats. Daily emissions data are available in annual and quarterly spreadsheets by state. A separate data set of hourly emissions data is formatted specifically for use with the population Sparse Matrix Operator Kernel Emissions (SMOKE) modeling system. The site also provides instructions for the free download and registration of the SMOKE model. Finally, raw emissions data from utility reports can be downloaded directly, providing hourly emissions information on a quarterly basis with separate reports for each unit. Recent reports are available in XML format; however, a majority of historical data from prior to 1998 are available only in a separate electronic data report data format. All forms of emissions data can be downloaded directly from EPA's FTP site, which facilitates the download of large amounts of data at once.

C. Compliance Data

EPA provides compliance data—essentially a summarization of annual emissions and allowance data—to determine whether a plant has sufficient allowances to cover annual emissions. Instead of aggregating at the unit level, EPA aggregates compliance data at the power plant level. Identification information includes facility identification (ORISPL), unit identification, and allowance account numbers. Descriptive fields include annual totals for allowances allocated, total allowances held, annual emissions, and the number of allowances remaining after deductions from annual emissions. Two additional fields show allowances banked and a compliance field showing emissions in excess of available allowances, which typically equals banked allowances because of nearly perfect compliance.

D. Air Quality and Deposition Data

EPA collects air quality data, including dry chemical deposition, atmospheric gas concentrations, and meteorological measurements. Most of these data sets span the time period from 1987 to 2010. The dry chemical deposition data set consists of 115 sites that record weekly ambient concentrations of SO_2, nitric acid, sulfate, nitrate, and ammonium, as measured by dry filters. The atmospheric gas concentrations data set includes hourly SO_2, nitrous oxides, and carbon monoxide values, as measured by gas analyzers. A final air quality data set uses 85

monitoring stations to record hourly ozone concentration measurements, temperature, humidity, solar radiation and wind speed.

EPA also releases deposition estimates calculated by the Multilayer Model, which includes output for concentration, dry deposition velocity, and dry deposition flux. Data for each of these variables are available at hourly, weekly, seasonal, and annual time scales. Deposition data are critical for measuring changes to ecosystem health from reductions in air pollution.

VI. Limitations of the Acid Rain Program

As indicated by the large benefit-to-cost ratio of 40:1 provided by Chestnut and Mills (2005), it is clear that the ARP could have further achieved cost-effective benefits by encouraging more reductions through a lower cap. Although Congress instated the ARP to capture natural resource benefits associated with emissions reductions, the majority of estimated benefits actually came from improvements in human health, as lower levels of particulate matter (a pollutant associated with SO_2 emissions) reduced morbidity and mortality. But when Congress instated the ARP, consensus scientific opinion about the impact of particulate matter on human health had yet to be established.[9] Without a mechanism to adapt allowance levels in light of new information, which emerged shortly after passage of the 1990 legislation establishing the ARP, the program was destined to achieve suboptimal emissions reductions.

VII. Lessons from the Acid Rain Program

Future research should aim to incorporate mechanisms that allow for the adaptive management of allowance levels given new information. To this end, Burtraw et al. (2009) propose a symmetric safety valve that allows for the removal of allowances if a certain price floor is reached. This type of program design would automatically respond to new information about costs, but it would not respond to new information about the benefits of emissions reductions. An important next step for researchers is to move beyond a cost trigger for this mechanism and identify scientific and economic indicators that might be used by an expert agency to justify the withdrawal of allowances (changing the cap). Finally, researchers might suggest a political pathway that requires certain experts to review allowance allocations at a

[9] Even when one counts only natural resource benefits and other nonhealth benefits, estimated costs of the ARP roughly equal estimated benefits (Chestnut and Mills 2005; Bhanzhaf et al. 2006)

particular frequency. Incorporating these aspects would enable the adaptive management of allowance allocations and help ensure that cost-effective benefits are not left on the table.

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