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The 1990 Clean Air Act Amendments: Who Got Cleaner Air – and Who Paid For It?

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Abstract

Title IV of the 1990 Clean Air Act Amendments (CAAA) required the dirtiest coal-fired utilities to cap their SO_2 emissions at 5.8 million tons per year (approximately 33% below their 1990 levels) starting in 1995. At the same time, there was a major regulatory regime change with respect to the regulation of coal-fired utilities, shifting from command-and-control emission standards to a system of tradable allowances. We examine the distribution of costs and health benefits associated with the air quality improvements mandated under Title IV; we also compare it to the distribution of costs and health benefits that might have arisen from a comparable reduction in emissions using a command-and-control system. Using data for 148 coal-fired utilities, we find as expected that the benefits of reduced SO_2 emissions under Title IV greatly exceeded the costs: we estimate benefits of nearly \$56 billion and costs of only \$558 million. Because of the location of the power plants the benefits (and costs) are concentrated in the northeastern, north central, and southeastern states. When we examine the socio-economic distribution of net benefits, we find that the poor received slightly lower benefits on average from Title IV, which could raise environmental justice concerns, but that the black and Hispanic communities received a disproportionately large share of the benefits relative to their costs. Comparing the distribution of costs and benefits under trading versus a hypothetical command-and-control system requiring the same overall emission reductions, we find that the trading system led to sizable savings (16.8%) in abatement costs, but permit buyers tended to have higher-impact emissions than sellers, offsetting the cost savings. This result suggests a possible role for spatially-based 'exchange rates' in permit trading.

I. Introduction

Prior to the passage of Title IV of the 1990 Clean Air Act Amendments (CAAA), there had been a lively debate involving Congress, the Environmental Protection Agency (EPA), and academics, about the need for reducing sulfur dioxide (SO_2) emissions due to the problem of acid rain. Acid rain is formed when SO_2, released as a gas from coal when it is burned at high temperatures, reacts with water in the atmosphere to form sulfurous acid and sulfuric acid. These two acids then return to earth in the form of raindrops and dry particles. In addition to domestic pressure, Canada was putting political pressure on the U.S. to decrease acid rain. Just after the passage of the CAAA the U.S. and Canada signed the Canada-United States Air Quality Agreement, aimed at controlling transboundary acid rain. How damaging is acid rain? The National Acid Rain Precipitation Assessment Program found that acid rain causes minor damage to crops and modest damage to aquatic life in acidified lakes and streams. Burtraw et al (1997) estimate the expected environmental benefits from recreational activities, residential visibility, and morbidity to be about $13 per capita in 1990.

On the other hand, SO_2 also combines in the atmosphere with ammonia to form sulfates, fine particulates (PM_{10} and $PM_{2.5}$) which have been shown in several studies to contribute significantly to pre-mature mortality. Thus, even if acid rain has only a marginal environmental impact, reductions in SO_2 emissions have additional (and potentially much larger) economic benefits, through reduced mortality. EPA estimates that the human health benefits of the Acid Rain Program will be around $50 billion annually (due to decreased mortality, fewer hospital admissions and fewer emergency room visits) by the year 2010.

Coal from fossil-fuel fired electric utilities accounts for most of SO_2 emissions in the United States. Title IV of the 1990 CAAA set an annual 9 million ton cap on SO_2 emissions from all fossil fuel fired electric utilities. This cap, which is to be fully achieved by 2010, requires the affected electric utilities to reduce their aggregate SO_2 emissions by 10 million tons below their 1980 levels. This cap will be implemented in two phases. During Phase I, from 1995 to1999, 110 of the dirtiest coal-fired utilities must reduce their aggregate SO_2 emissions to 5.8 million tons per year (about 33% below their 1990 levels). During Phase II, which began in 2000, nearly all major fossil-fuel fired plants are subject to the 9 million ton cap on annual aggregate SO_2 emissions, which meant that the Phase I plants had to make additional reductions.

Title IV, along with requiring substantial SO_2 reductions, also abandoned the command-and-control approach to the regulation of utilities, where utilities were required to meet individual emission standards set by regulators, in favor of a more flexible, cost-efficient tradable permit approach. This more flexible approach made the substantial SO_2 reduction politically feasible and is widely believed to have led to tremendous cost savings relative to the command-and-control approach. Keohane (2003) estimated that the system of allowance trading resulted in cost savings between $150 million and $270 million annually, compared to a uniform emissions-rate standard.

Title IV allows permits to be bought and sold freely anywhere in the continental United States.[1] The policy of no restrictions on the buying or selling of permits could result in an efficient allocation of SO_2 reductions if emissions had the same marginal benefit everywhere across the United States – though our calculations of health benefits show substantial heterogeneity across plants in the marginal benefit per ton of emissions reduction. In addition,

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[1] The only time a plant would be prevented from buying allowances to emit more SO_2 would be if that plant was located in a county which was in violation of the National Ambient Air Quality Standard (NAAQS) for SO_2, which were set at levels to prevent local adverse health outcomes. However, this has rarely posed a problem for permit trading since the Title IV cap requires a significantly greater reduction of aggregate SO_2 emissions than what is required to meet the NAAQS for SO_2.

allowing permits to be bought and sold freely may inadvertently create a divergence between the people who are paying for the SO_2 reductions and those that are benefiting from the reductions. Morgan and Shadbegian (2003) find that the SO_2 trading program may have inadvertently resulted in some environmental injustices – mainly higher levels of emissions in disproportionately poor and minority areas.[2]

In this paper we extend the work of Morgan and Shadbegian by examining the distribution of the costs and benefits associated with air quality improvements that occurred under Title IV of the CAAA. In one scenario, we measure these improvements relative to the level of emissions under the former command-and-control regime, which allowed a greater level of emissions. In another scenario, we measure the improvements relative to a counterfactual distribution of emissions based on requiring emissions reductions similar in magnitude to those under Title IV, but imposed proportionately on all plants without the possibility of trading. In these scenarios, we examine the spatial distribution of costs and benefits both in terms of the states and regions being affected and the socio-economic composition of the affected population.

The vast majority of dollar-valued benefits from air pollution abatement arise from the impact of airborne particulates ($PM_{2.5}$ and PM_{10}) on premature mortality. A 1995 EPA study reports that of the estimated $22.2 trillion worth of benefits derived from the Clean Air Act of 1970, reductions in particulate-related mortality contributed more than $20 trillion. We use a spatially-detailed air pollution dispersion model (the Source-Receptor Matrix) to evaluate the impact of SO_2 emission reductions from each plant on county-level concentrations of particulates during Phase I of Title IV. Using existing evidence on the connection between particulate

[2] According to the Office of Environmental Justice at EPA, environmental justice exists when "no group of people, including racial, ethnic, or socioeconomic group, … bear[s] a disproportionate share of the negative environmental consequences resulting from industrial, municipal, and commercial operations."

exposures and mortality, we translate the reductions in secondary particulate concentrations in each county in the U.S. into the dollar benefits from reductions in mortality.

Who pays for the improvements in air quality? One possible answer is "nobody", if efficiency improvements resulting from the new emissions trading system (e.g. more flexible production switching, less uncertainty about regulatory requirements) outweigh the additional abatement costs on a plant-by-plant basis. A more likely scenario is that some plants face higher costs of abatement, which are passed along to their customers. If some plants increase their emissions and buy additional allowances, the population affected by the worsening air quality will be "paying" some of the costs of the greater air quality improvements near other plants that reduced their emissions in order to sell the allowances. In addition to comparing the costs and benefits that arise from reduced SO_2 emissions under Title IV, we simulate the impact of requiring a comparable reduction in overall SO_2 emissions under the old command-and-control regime, assuming that a uniform emission standard is in place at all plants.

Arrow et al (1996) argue that along with a cost-benefit analysis measuring the aggregate net benefits from a regulation, a good analysis will also examine the distributional consequences. In this paper we compare the overall net health benefits that were achieved under Title IV along with the spatial distribution of those net benefits to test whether there were unforeseen consequences of the regulatory change in terms of adverse impacts on particular regions or socio-economic groups. The findings will indicate whether these distributional impacts are of only second-order importance compared to the overall net benefits, or whether they are sufficiently large for policy-makers to take them into account when considering future market-oriented regulatory reforms.

Using data for the 148 dirtiest coal-fired utilities we find, as expected, that the aggregate benefits in 1995 caused by reductions in SO_2 emissions under Title IV greatly exceed their costs: we get benefits of $56 billion (a bit larger than EPA's estimates of total benefits of $50 billion by 2010) and costs of only $558 million. Therefore, the net benefits from the SO_2 reduction are roughly $55 billion or $100 in benefits for every $1 in abatement costs. The net benefits are positive in every EPA region, but are highly concentrated. We find that nearly 90% of the benefits and costs of the overall reductions under Title IV are concentrated in 4 regions – the northeastern, north central, and southeastern states. In terms of the socio-economic distribution of net benefits, we find that minority groups (blacks and Hispanics) receive a greater share of the benefits than of the costs. The poor are the only group raising any environmental justice concerns, receiving a slightly higher share of the costs than of the benefits. Comparing the consequences of requiring similar overall emissions reductions using command-and-control regulation, we find that trading results in a significant cost reduction ($94 million or 16.8%). However, shifts in the spatial distribution of emissions go in the other direction, with permit buyers having higher-impact emissions than permit sellers. This tends to reduce the benefits from the trading system, and suggests the possibility of developing some sort of 'exchange rate' for allowance trades, based on the relative emission impacts of the parties involved.

The rest of the paper is organized as follows. In section II we present background information on Title IV of the CAAA of 1990. Section III contains a brief survey of the literature on studies examining various aspects of the Title IV trading program and various aspects of environmental justice. Section IV describes the methodology we use to estimate both the health benefits and the costs of SO2 abatement under Title IV and section V describes our sample of plants. In section VI we discuss our findings and we end with some concluding remarks in Section VII.

II. Title IV: Background Information

Title IV of the CAAA completely changed the way coal-fired utilities were regulated in the U.S. Prior to Title IV utilities were regulated by a command-and-control regime that targeted the sulfur content of the coal used at each individual plant. Title IV established a cap-and-trade program that set a cap on total SO_2 emissions, distributed allowances among generating units equal to that cap, and allowed plants to freely trade these allowances among their own units, to sell them to other plants, or to bank them for future use. The only requirement faced by a plant under the trading program is that it must have enough allowances at the end of the year to cover each ton of SO_2 emitted that year. Thus, the allowance trading program instituted by Title IV provides much greater flexibility to achieve any given emission standard because utilities which face high marginal abatement cost may purchase SO_2 permits from utilities which face lower marginal abatement costs.

The goal of Title IV was to reduce aggregate SO_2 emission levels to approximately 9 million tons by 2010, roughly half of the 1980 level. The reduction was to be achieved in two phases. Phase I (1995-1999) targeted the dirtiest 110 power plants (with 263 generating units). These generating units, called the Table A units, were required to reduce their emissions to 7.2 million tons per year starting in 1995, 6.9 million tons per year in1996, and then 5.8 million tons per year from 1997-1999. The Table A units emitted 8.7 million tons of SO_2 in 1990 and only emitted 4.5 million tons in 1995 (roughly 50% less). The number of allowances a unit received was based on its average 1985-1987 heat input times an average emission rate of 2.5 lbs of SO_2 per million BTUs of heat input. Each allowance gave a unit the right to emit one ton of SO_2, and the unit could only emit an amount of SO_2 equal to the number of allowances held.[3]

[3] Generating units face a fine of $2000 for each ton of SO_2 emitted for which they do not have an allowance.

Phase II, which began in the year 2000, brought the smaller generators – generators that have an output capacity of 25 megawatts or greater – under the cap-and-trade system.[4] In addition to imposing constraints on the smaller and cleaner units, the Table A units are required to make additional reductions in their SO_2 emissions – reducing their overall emissions by another 3.4 million tons, down to 2.4 million tons by 2010. Annual allowance allocations to each unit are based on an average emission rate of 1.2 lbs of SO_2 per million BTUs of heat input, a much stricter standard than the 2.5 lbs during Phase I.

In 1995 SO_2 emissions dropped dramatically. Phase I plants emitted a total of only 4.9 million tons, a reduction of 4.6 million tons – 3.2 million tons more than was required. In fact, SO_2 emissions started to decrease right after the passage of Title IV, even before the trading system was in place. Several explanations have been offered for the pre-1995 reduction. Plants may have complied early in order to pass on to consumers the additional cost of low-sulfur coal or the cost of installing scrubbers. Some states amended their State Implementation Plans (SIPs) requiring utilities to reduce their emissions before the first year of Phase I. The most likely explanation is that railroad deregulation made it cheaper to transport low-sulfur coal to Midwest electric power plants, the geographic area that experienced the most reductions in SO_2 emissions between 1985 and 1993 (Ellerman and Montero, 1998).

Another important feature of the SO_2 allowance market is that allowances that are not used in one year may be banked and used in any subsequent year. That is, a plant may reduce emissions below their annual allocation and deposit the extra allowances in an emissions bank. These "banked" allowances are perfect substitutes for future year allowances, and may be used or sold. Banking during Phase I could help plants adapt to the more stringent limits imposed

[4] Some of these smaller generators joined Phase I, under the "substitution" and "compensation" provisions, and are included in this analysis.

under Phase II by smoothing the required reductions over time. This explanation is borne out by experience: plants banked over 11.5 million allowances during Phase I (1995-1999), then used 1.2 million of these banked allowances in the first year of Phase II (2000), followed by 1.08 million allowances in 2001 and another 650,000 million allowances in 2002. This suggests that the extra abatement during Phase I was intentional (rather than being an unexpected result of lower than expected prices for low-sulfur coal).

III. Literature Review

A. SO_2 Trading Program

Long before the advent of emissions trading, Gollop and Roberts (1985) estimated that a cost-effective allocation of pollution abatement across electrical utilities would result in a nearly 50% reduction in pollution abatement costs, suggesting potentially large savings from emissions trading. Since the passage of the CAAA, many papers, including Burtraw et al (1997), Joskow et al (1998), Schmalensee et al (1998), Carlson et al (2000), Popp (2000), Keohane (2002,2003), Ellerman (2003), and Shadbegian and Morgan (2003), have examined various aspects of the actual SO_2 allowance trading program including its cost savings, environmental effectiveness, spatial patterns of abatement, pollution control innovations, and the efficiency of the banking of permits. The potential success of any pollution permit-trading program depends on the efficiency of the market of the tradable permits. Joskow et al (1998) assess the efficiency of the market for SO_2 permits by comparing the price of permits auctioned by EPA between 1993 and 1997 with private market indices. If the market for SO_2 permits is efficient then EPA auction prices and private market prices will be the same. Joskow et al find that by the end of 1994 these prices were virtually identical and thereby conclude that the private market for tradable permits was relatively efficient. Schmalensee et al (1998) also conclude that the private market for tradable permits was relatively efficient by noting the growth in level of the trading volume in the market: 1.6 million, 4.9 million, and 5.1 million allowances were traded in 1995, 1996, and 1997, respectively.

Keohane (2003) estimates that using a system of tradable allowances resulted in annual cost savings between \$150 million and \$270 million compared to a uniform emissions-rate standard. However, Carlson et al. (2000) conclude that the large decrease in abatement costs during the beginning of Title IV relative to the original estimates resulted more from a technological change that reduced the cost to switch to low sulfur coal and the decrease in the price of low sulfur coal rather than the ability to trade permits per se. Shadbegian and Morgan (2003) examine the impact of the stringency of SO_2 regulations on the productivity of electric utilities. They find that a 10% increase in regulatory stringency reduced productivity by 0.66% before Title IV, while during Title IV that same increase only reduced productivity by an insignificant 0.04%. This productivity gain translates into 31 million more kilowatts (kwh) of electricity –equivalent to \$1.5 million cost savings, even at \$0.05/kwh.

Ellerman (2003) addresses many issues involving both Phase I and Phase II of the SO_2 trading program including whether or not the over 11 million allowances "banked" during Phase I was optimal. Under reasonable sets of assumptions regarding both the discount rate and the expected growth of SO2 emissions during the banking period, Ellerman concludes that the level of banking that occurred was consistent with rational, cost-minimizing behavior on the part of the utilities.

One reason economists have advocated the use of market-based mechanisms to protect the environment is the potential for gains from induced technical change. Popp (2003) and

Keohane (2002) have both found evidence to support this claim. Popp finds that, prior to 1990, regulation required many new plants to install scrubbers with a 90% removal efficiency rate which created incentives that led to innovations which lowered the cost of operating scrubbers, yet did little to increase the ability of scrubbers to reduce pollution. However, Popp also finds that since the passage of the CAAA of 1990 there have been technological innovations that have improved the removal efficiency of scrubbers. Keohane examines the choice of pollution abatement technique under command-and-control versus a system of tradable permits and finds that fossil fuel fired electric utilities subject to Title IV were, for a given increase in the cost of switching to low sulfur coal, more likely to install a scrubber.

One possible complication for an allowance trading system arises when emissions from different sources have different impacts on human health (or other benefits). Baumol and Oates (1988, Chapter 12) note that differences in health impacts across different emission sources could lead to undesirable results, if high-impact sources are buying allowances from low-impact sources on a one-for-one basis. Tietenberg (1995) reviews the literature on the spatial effects associated with marketable permits, noting that the first-best option (different prices for each source) greatly complicates the trading process, so various second-best options have been proposed. Concerns about "hot spots" (unacceptably high local concentrations of pollutants) are addressed under Title IV by its prohibition on trading in counties which do not meet air quality standards, but this does not solve the broader problem of differences in emission impacts across sources.

B. Distribution of Pollution

During the past decade there has been an increasing number of studies that examine various aspects of environmental justice – polluting plants' location decisions, expansion decisions of hazardous waste facilities, fees paid to communities to "host" facilities, plant emissions, and regulator decisions – in a formal multiple regression framework. Previous anecdotal evidence (see GAO, 1983 and United Church of Christ, 1987) suggests that firms tend to locate their polluting plants in areas with a greater percentage of poor people and minorities. In the first formal econometric study on the siting decisions of polluting plants, Been and Gupta (1997) examine the location decisions of commercial hazardous waste treatment storage and disposal facilities (TSDFs) in 544 communities across the United States. In their study Been and Gupta find no statistical evidence that TSDFs were more likely to be sited in neighborhoods that were disproportionately African American at the time of siting, but do find evidence that TSDFs were more likely to be sited in disproportionately Hispanic areas. Furthermore, Been and Gupta find that poor neighborhoods are actually negatively correlated with TSDF sitings. Wolverton (2002a) examines the location decisions of plants in Texas which emit enough toxic waste that they are required to report to the Toxic Release Inventory (TRI). Wolverton's results show that if one considers the socioeconomic characteristics of the community at the time the plant is sited, that contrary to the anecdotal evidence, race does not matter and poor communities actually attract disproportionately *fewer* polluting plants – a finding similar to Been and Gupta.

Hamilton (1993, 1995) examines whether exposure to environmental risk is related to socioeconomic characteristics of a neighborhood and political activism. Specifically, Hamilton examines the relationship between the net capacity expansion decisions of commercial hazardous waste facilities and race, income, education, and voter turnout (level of political activity) and finds that the decision to expand net capacity is not significantly related to any of the socioeconomic variables, but is significantly negatively correlated with voter turnout. On the other hand, Jenkins, Maguire, and Morgan (2004) show that counties with greater percentages of minority residents receive lower "host fees" for the siting of landfills, while richer counties receive higher host fees, results consistent with the idea of environmental injustice.

Three additional studies examine the relationship between pollution emissions and the socioeconomic characteristics of communities to assess the validity of the claim of environmental injustice: Arora and Cason (1999), Wolverton (2002b), and Gray and Shadbegian (2004). Arora and Cason examine 1993 TRI emissions for the entire U.S. at the zip code level finding evidence of racial injustice only in the south. More specifically, Arora and Cason find that race is only significantly positively related to TRI releases in non-urban areas of the south. Wolverton (2002b) examines the relationship between TRI releases and socioeconomic characteristics of communities in Texas and finds that plants tend to reduce TRI releases *more* in minority neighborhoods than in non-minority neighborhoods, exactly the opposite of the claim of environmental racism. Gray and Shadbegian (2004) examine the relationship between SO_2, PM10, BOD, and TSS emissions of pulp and paper mills and socioeconomic variables finding mixed results. For all four pollutants Gray and Shadbegian find that plants with a greater percentage of poor nearby emit more pollution, a result consistent with environmental injustice, but that plants with more minorities nearby actually emit *less* pollution.

Finally Becker (2003), using establishment-level data on manufacturing plants from the U.S. Census Bureau's Pollution Abatement Costs and Expenditures (PACE) survey, examines the relationship between air pollution abatement expenditures and community demographics. Becker finds that, after controlling for a number of plant-level characteristics and levels of federal, state, and local regulation, communities with higher homeownership rates and higher per capita income enjoy greater pollution abatement activity from their nearby plants.

IV. The Benefits and Costs of Cleaner Air

A. Benefits from Cleaner Air

We identify the benefits of reducing SO_2 emissions (SO2BEN) from a given source with the change in mortality risk from exposure to ambient particulate concentrations caused by those SO_2 emissions. These health benefits are measured using a simplified linear damage function, based on estimated parameters from the literature:

SO2BEN = SO2DIFF*AIR_QUAL_TC * HEALTH_CHG * POP * VSL.

AIR_QUAL_TC is the transfer coefficient – the change in air quality (ambient particulates) per unit change in SO_2 emissions (SO2DIFF). HEALTH_CHG is the change in mortality risk to the affected population due to the changes in air quality. POP is the size of the affected population, and VSL is the dollar value placed on reducing mortality.

We measure the changes in air quality at any given location using the Source-Receptor (S-R) Matrix Model, as described in Latimer (1996) and Abt (2000). The S-R Matrix model was originally calculated using the Climatological Regional Dispersion Model (CRDM). The model incorporates data on pollution emissions from 5,905 distinct sources in the U.S., along with additional sources from Mexico and Canada.[5] The S-R Matrix relates emissions of specific pollutants from each source to the resulting ambient concentrations of each pollutant in every

[5] Emissions sources in the U.S. combine ground-level sources, county-level sources and individual sources. Ground-level sources were estimated for each of the 3,080 contiguous counties, while elevated sources were grouped according to effective stack height. Point sources with an effective stack height greater than 500 meters were modeled as individual sources of emissions. All the sources in the same county that had an effective stack height less than 250 meters were grouped together into a single county-level source, as were those with effective stack heights between 250 meters and 500 meters . In total there were 5,905 U.S. sources modeled in the S-R matrix (ground-level sources were also aggregated at the county level).

county in the U.S. Specifically, for a change of one ton in emissions of a particular pollutant from a particular source, this matrix yields the necessary transfer coefficients: the county-by-county changes in annual average pollutant concentrations. The S-R Matrix transfer coefficients are a function of many factors including wet and dry deposition of gases and particles, chemical conversion of SO_2 and nitrogen oxide (NO_X) into secondary particulates, effective stack height, and several atmospheric variables (wind speed, wind direction, stability, and mixing heights). We use the impact of SO_2 emissions on ambient concentration of $PM_{2.5}$ in each county to measure AIR_QUAL_TC.

Our measure of HEALTH_CHG concentrates on the long-term mortality effects of primary and secondary particulate matter -- an assumption consistent with past studies (Rowe et al., 1995; Levy et al., 1999). Since our study is focused on the health benefits of reduced SO_2 emissions we concentrate on the health benefits from lower concentrations of secondary particulates that result from SO_2 emissions. We use the findings from the American Cancer Society study, the most comprehensive analysis of long-term mortality effects from air pollution to date (Pope et al., 1995). They find approximately 4% higher mortality rates in people exposed to a 10 $\mu g/m^3$ increase in PM_{10} concentrations (95% confidence interval: 2%, 6%). We assume that the point estimate is applicable to the secondary particulates formed from SO_2 (Pope et..al. found similar numbers for sulfate particles in their study).[6]

Our estimate of the exposed population, POP, is based on county-level data from the 1990 Census of Population. This data identifies the total number of people living in each county (and hence the number affected by the average ambient pollution concentrations in that county). In addition, it provides information on the socio-economic characteristics of each county's

[6] Chay and Greenstone (2003a, 2003b) examine the effect of particulate exposures on infant mortality, and obtain impacts of a similar magnitude, measured in terms of increased mortality rates.

population (e.g. income, age, race), which helps us examine issues of environmental justice.

Finally, to place a dollar value on premature mortality, we use a recent EPA (1997) benefit-cost analysis that estimated the value of a statistical life (VSL). The EPA study pooled contingent valuation and wage-risk studies to produce a central estimate of $5.4 million (in 1995 dollars) per life saved. Note that our calculations assign constant values of the VSL and HEALTH_CHG terms for the entire population. Each exposed person faces the same average dollar harm from exposures to particulates, allowing for neither differences in sensitivities for different populations nor differences in valuation.[7] Note also that the very large estimates we obtain for the benefits of reducing SO_2 emissions could be interpreted as a combination of these two factors: one could get smaller benefits by assuming either smaller health effects or a lower value of statistical life.

B. Costs of Cleaner Air

There are three options (or combinations of options) available to plants to comply with Title IV: installing a scrubber, switching to low sulfur coal, or continuing to emit SO_2 and buying allowances. We use two measures of the cost of abating a ton of SO_2 emissions. Our first measure of cost (COST1) is based on the method each plant actually used to comply with Title IV, given the option of purchasing permits. Based on Ellerman et al (1997) we have an average cost of abatement for each of the 374 units (plant-boiler observations) affected by Title IV during Phase I – this includes the 263 units required to reduce their SO_2 emissions by Title IV and 111 units which "opted into" Phase I. In 1995, the average cost per ton of "switching" and

[7] Our data would readily permit the calculation to differ in sensitivity and valuation for different subpopulations – if one could generate a consensus on how to quantify such differences, a politically charged issue that we avoid here.

"scrubbing" is $153 and $265 respectively, while the average cost of a permit is $128.50.[8] Our second measure of abatement cost (COST2) is based on Keohane (2003), which models each plant's abatement costs based on its decision to install a scrubber or not. This decision is evaluated first under the Title IV trading program and then under a traditional command-and-control regulation (no trading) scenario designed to generate the same aggregate SO_2 emission reductions achieved under the 1990 CAAA.[9] Keohane estimates the emissions and abatement costs at each of the plants under emissions trading and command-and-control regulation, and the differences in costs between the two regimes provide our second measure of abatement costs.

Who pays these extra abatement costs? One possible answer is "nobody", if efficiency improvements resulting from the new emissions trading system (e.g. more flexible production switching, less uncertainty about regulatory requirements) outweighed the additional abatement costs on a plant-by-plant basis. However, a more likely scenario is that plants facing higher costs of pollution abatement will pass along these costs to their customers. We assume that all of the additional costs are passed along to the utility's customers, and further assume that all customers live within the state where the utility is located.[10] We use the 1990 Census of Population to allocate each plant's abatement costs equally to all people living within that state, with the different socio-economic groups receiving benefits and costs proportional to their share in the overall population.

V. Sample Coverage

Phase I of Title IV regulated the emissions of 263 generating units (the Table A generating units) owned by 110 plants. An additional 38 "substitution and compensation" plants

[8] We would like to thank Denny Ellerman for providing us with this data.
[9] We would like to thank Nat Keohane for providing us with this data.

(111 generating units) “opted into” Phase I, bringing the final total to 374 generating units. Our sample consists of all 148 plants and their 374 generating units. The geographic distribution of these plants – heavily concentrated in the Midwest - is shown in Figure 1.

In Table 1 we present information on SO_2 emissions and the allocation of SO_2 allowances obtained from the EPA’s Allowance Tracking System (ATS).[11] The 148 plants in our sample emitted a total of 9.5 million tons of SO_2 during 1990, the year Title IV was passed. By 1995, our 148 plants had reduced their SO_2 emissions by 4.6 million tons from their 1990 levels, cutting them almost in half, although Title IV had only required them to reduce emissions by 15%, to 8.1 million tons.

VI. Distribution of Benefit and Costs

In Table 2 we present two scenarios of health benefits and abatement costs. In Scenario 1 we calculate the benefits and costs associated with the actual 1995 SO_2 emissions reductions (costs are based on Ellerman et al (1997)): counterfactual SO_2 emissions minus actual emissions. The counterfactual emissions in 1995 are those we would have observed in the absence of the CAAA of 1990 and are the same as those presented in Ellerman et al (1997). In Scenario 2 we compare the costs and benefits arising from the two different policy regimes (permit trading and command-and-control) for the same aggregate reduction in SO_2 emissions (based on Keohane (2003)). A visual comparison of the benefits from reducing SO_2 emissions under the two scenarios can be seen in Figures 2 and 3. Not surprisingly, given the concentration of the plants in the Midwest and the pattern of airflow from west to east, the benefits that result from the large reductions in emissions in Scenario 1 are highly concentrated geographically. Scenario 2

[10] If we had data on cross-state electricity sales, we could adjust our cost calculations to reflect this.
[11] We would like to thank Denny Ellerman for providing us with this data.

involves a reallocation of emissions reductions across plants, so we see both losers and winners in Figure 3.

As expected, the aggregate benefits in 1995 resulting from reductions in SO_2 emissions from the 1995 counterfactual levels far outweigh their costs: we get benefits of nearly \$56 billion and costs of only \$558 million. An alternative assumption on abatement costs, that the actual cost of a ton of abatement is equal to the permit price (\$128.5 in 1995), results in total abatement costs of only \$496 million. In either case these increased abatement costs are dwarfed by the increased benefits from the SO_2 reduction, which are roughly 100 times as large.

In Scenario 2 we find that allowing permit trading results in a sizable reduction in abatement costs (\$94 million or 16.8%), relative to a hypothetical command-and-control system that achieved similar emissions reductions. These cost savings are outweighed, however, by the tendency of allowance buyers to have higher-impact emissions than allowance sellers (explored in more detail later), which reduces the benefits from the reductions in SO_2 emissions due to Title IV. These results indicate a possible need for some sort of spatially-explicit 'exchange rate' system to adjust for these differences in emissions impact across sources.

Table 3A contains the distribution of benefits and costs under Scenario 1 across the 10 different EPA regions. Even though the net benefits are positive in every region, they are highly concentrated across regions. As seen earlier in Figures 2 and 3, the overwhelming majority of the benefits (89%) are concentrated in four regions (2, 3, 4, and 5). In addition, three of these regions (3, 4, 5) pay a very large percentage of the overall costs (90%). Regions 4, 5, and 7 all pay a higher percentage of the costs than they receive in terms of health benefits. Region 5 (the North Central states) is the biggest relative loser, paying 45% of the costs while only receiving 26% of the benefits. On the other hand, Regions 1 (New England) and 2 (NY and NJ) are the biggest relative winners, only paying 0.2% and 1.2% of the costs while receiving 6% and 17% of the benefits, respectively.

In Table 3B we compare the net benefits per capita in each region and this leads to a somewhat different ranking of relative winners and losers than what we observed with the shares of benefits and costs. Regions 1-5 each derive more than $249 per capita net benefits. Region 3 (the mid-Atlantic states) receives the highest level of net benefits, $502 per capita, followed by regions 2, 1, 5 and 4. Interestingly region 5, which was the biggest relative loser in terms of shares of benefits versus shares of costs, does reasonably well in terms of net benefits (nearly $300 per capita), due to the relatively large population in region 5 (and because benefits are much larger than costs in absolute magnitude). The distribution of net benefits per capita is very similar for the regions under uniform standards versus permit trading (Scenario 2). Under permit trading regions 1, 2, and 3 have lower net benefits while regions 4, 6 and 7 each have higher net benefits, although the changes under Scenario 2 are much smaller than those under Scenario 1.

Tables 4A and 4B contain the benefits, costs, and net benefits for the 48 contiguous states and the District of Colombia. As shown in Figures 2 and 3, the benefits and costs of SO_2 emissions reduction vary considerably across states. Table 4A presents these benefits and costs as percentages of national totals, while Table 4B presents them in dollars per capita. The net benefits under Scenario 1 are positive for all states, but the costs of abatement are borne by a relatively small number of states (those containing the 148 plants). The largest share of the cost is incurred by states in regions 3, 4 and 5: Ohio (24%) followed by Indiana (14%), Tennessee (13%), and West Virginia (10%). Each of these states has a larger share of the costs than the benefits. Other states whose share of the costs exceeds their share of the benefits include Florida, Georgia, Illinois, Kentucky, and Missouri. Five states exceed $500 in benefits, with most of these in region 3 - Maryland, Ohio, Pennsylvania, Washington DC, and West Virginia. Six other states have net benefits greater than $350 per capita: Delaware, Indiana, Kentucky, New Jersey, Tennessee, and Virginia.

To examine whether or not there are any environmental justice concerns surrounding the SO_2 trading program we consider the distribution of benefits and costs received by different demographic groups, focusing on the results for Scenario 1. To do this, we used the demographic composition of every county in the U.S., assuming that everyone in the county was equally affected by changes in pollution and by changes in electricity prices, to calculate the fraction of national benefits and national costs received by each group. Table 5A shows the per capita benefits, costs, and net benefits from each scenario, for the total population and for five different demographic groups: blacks, Hispanics, poor (the population living below the poverty line), kids (the population under the age of 6), and elders (the population over the age of 65). Table 5B then shows the ratio of benefits to costs for the different groups. The results show that both the Hispanic and black communities received a much larger share of the benefits than the costs, although this arises for different reasons, with the black community receiving a higher share of the benefits and the Hispanic community receiving a lower share of the costs. Kids and elders received roughly the same share of benefits and costs as the overall population. On the other hand, the poor received slightly less of the benefits than of the costs under Scenario 1, which could raise some environmental justice concerns.

To further examine the distribution of benefits and costs along demographic lines, we calculated them separately for each of the plants in our sample, asking whether that plant's changes in emissions under Scenario 1 led to a disproportionately large increase in costs (relative to benefits) for any of these groups. For each group we then calculated the fraction of plants that had disproportionately large costs relative to benefits. These numbers are presented in Table 6. A number greater than 50% indicates that changes in emissions had negative effects more often than positive ones on that demographic group. Since these calculations are not weighted by plant size, they need not give the same results as those in Table 5. The results are, on the whole, reasonably similar to those in Table 5, although we do not see the poor being disadvantaged here (only kids show a disproportionately negative effect). As in Table 5, the black and Hispanic communities do quite well – only 25% and 10% of the plants have a negative effect on these communities respectively. Therefore we conclude that any environmental justice concerns are small, and concentrated on the poor, rather than on the black or Hispanic community.

Finally, in Table 7 we examine differences in the benefits generated from reductions in SO_2 emissions. Table 7A shows the distribution of the benefits per ton of reduction across our 148 plants. The variation in these numbers across plants is based on a variety of factors, including effective stack height and meteorological conditions, though the principal determinant is the population density downwind. There are a few outliers at the top and bottom of the distribution, but most plants fall between $9,600 and $19,500 per ton in benefits. The plants towards the top of the distribution tend to be in places like Pennsylvania, while plants in Alabama, Florida, Georgia, and Mississippi tend to be near the bottom, although there is some within state variation as well. Furthermore, in Table 7B we find that plants which buy permits (to emit more SO_2) are more likely to be high-benefit plants, while plants that sell permits (and thereby emit less SO_2) are more likely to be middle- or low-benefit. This is reflected in the average benefits at buying and selling plants: the buying plants have a mean benefit of $17,519 while the selling plants have a mean benefit of $14,777. These differences are not huge, but it is still the case that the plants which are buying (selling) permits are those plants which yield the highest (lowest) benefits from abating a ton of SO_2. This result drives the negative impact of the trades on overall benefits observed in Table 2, and suggests that the allowance trading system might benefit from a spatially-based ‘exchange rate’ based on differences in the impacts of emissions across these plants.

VII. Concluding Remarks

In this paper we analyze plant-level information on fossil fuel fired electric utilities to examine the distribution of costs and health benefits associated with the air quality improvement achieved by Title IV of the 1990 CAAA and compare it to the distribution under a command-and-control regime. In addition to comparing the costs and health benefits that arise from reductions in SO_2 emissions under Title IV, we use data on abatement costs to simulate the impact of requiring a comparable reduction in SO_2 emissions under the old command-and-control regime, by assuming uniform emission standards at all plants. We examine the distribution of benefits and costs both in terms of the regions being affected and the socio-economic composition of the affected population.

Our results for Scenario 1 suggest that, as expected, the aggregate health benefits in 1995 caused by reductions in SO_2 emissions under Title IV greatly exceeded their costs. We estimate benefits of \$56 billion and costs of only \$558 million leading to \$55 billion dollars of net benefits from the SO_2 reductions. The net benefits are positive in every region of the country, but are highly concentrated across regions. In particular, nearly 90% of the benefits and costs are concentrated in regions 2-5 representing the northeastern, north central, and southeastern states. Maryland, Ohio, Pennsylvania, Washington DC, and West Virginia are the biggest winners in terms of per capita net benefits – all have per capita net benefits of \$500 or above. Six other states have net benefits greater than \$350 per capita: Delaware, Indiana, Kentucky, New Jersey, Tennessee, and Virginia.

In terms of the socio-economic distribution of net benefits under Scenario 1, we find little evidence for environmental justice concerns. The black and Hispanic communities receive a substantially greater share of the benefits associated with SO_2 abatement under Title IV than they do of the costs (higher benefits for the black community, lower costs for the Hispanic community). The poor do have a slightly higher share of costs than benefits, the only (weak) evidence supporting environmental justice concerns.

Our results for Scenario 2 compare the results from permit trading under Title IV versus a hypothetical command-and-control system with uniform emission standards that would achieve the same overall reduction. We find that permit trading saves a substantial fraction of the abatement costs, but the geographic shift in SO_2 emissions induced by permit trading goes in the other direction, generating a reduction in the abatement benefits. To understand the importance of shifts in emissions across plants for Scenario 2, we examine the distribution of the marginal benefits of reducing emissions across our 148 plants. The differences are not huge: the median benefit per ton is about $15,000 and 80% of plants fall between $10,000 and $20,000. However, when we consider which plants are buying or selling permits, we find that plants that buy permits tend to be high-benefit and plants that sell permits tend to be middle or low-benefit. This helps explain the negative net benefits from permit trading we find for Scenario 2, and raises the question of whether permits for emissions from different sources should have different values, depending on the impact of those emissions, perhaps using calculations of the sort performed here. Certainly these results highlight the importance of properly accounting for the benefits from emission reduction, since the changes in benefits in our models are estimated to be so much larger in absolute dollar terms than the changes in costs.

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Table 1 – Phase I Plants

	Phase I Plants*
SO_2 Emissions in 1990 (tons)	9,468,183
SO_2 Emissions in 1995 (tons)	4,902,778
Allowances in 1995	8,076,472
Boilers	374
Plants	148

* = Includes the 110 Table A plants plus the 38 "Substitution and Compensation" plants

Table 2 – Benefits and Costs

	Scenario 1	**Scenario 2**
Benefits	$55.94 billion	-$1,255 million
Costs	$0.56 billion	-$94 million
Net Benefits	$55.38 billion	-$1,161 million

Table 3A – Percentage Distribution of Benefits and Costs Across Regions

Region	STATES	SCENARIO 1	
		BENEFIT	COST
1	CT,MA,ME,NH,RI,VT	6.21%	0.19%
2	NJ,NY	16.84%	1.24%
3	DC,DE,MD,PA,VA,WV	23.69%	15.36%
4	AL,FL,GA,KY,MS,NC,SC,TN	22.05%	30.33%
5	IL,IN,MI,MN,OH,WI	26.19%	44.74%
6	AR,LA,NM,OK,TX	2.82%	0.00%
7	IA,KS,MO,NE	2.07%	8.14%
8	CO,MT,ND,SD,UT,WY	0.11%	0.00%
9	AZ,CA,NV	0.02%	0.00%
10	ID,OR,WA	0.00%	0.00%

Table 3B – Average Dollar Per Capita Distribution of Benefits and Costs Across Regions

Region	SCENARIO 1			SCENARIO 2		
	AVERAGE BENEFIT	AVERAGE COST	AVERAGE NET BEN	AVERAGE BENEFIT	AVERAGE COST	AVERAGE NET BEN
1	256.2	0.1	256.1	-20.1	-0.1	-20.0
2	354.7	0.2	354.4	-27.1	0.1	-27.2
3	505.5	3.3	502.2	-25.2	-1.4	-23.8
4	252.7	3.5	249.2	1.5	0.1	1.4
5	303.7	5.2	298.5	-1.9	-1.6	-0.3
6	51.3	0	51.3	5.5	0	5.5
7	93.2	3.7	89.5	19.4	1.1	18.3
8	7.5	0	7.5	0.0	0	0.0
9	0.3	0	0.3	0.1	0	0.1
10	0.3	0	0.3	0.0	0	0.0

Table 4A – Cross-State Shares in Benefits and Costs
(% of national totals for Scenario 1)

State	Benefit	Cost
AL	2.10	1.58
AR	0.56	0.00
AZ	0.01	0.00
CA	0.01	0.00
CO	0.05	0.00
CT	1.77	0.00
DC	0.56	0.00
DE	0.58	0.00
FL	3.10	3.81
GA	3.73	6.11
IA	0.43	0.00
ID	0.00	0.00
IL	4.69	6.10
IN	4.59	13.61
KS	0.20	0.00
KY	3.17	5.97
LA	0.74	0.00
MA	2.73	0.09
MD	4.82	1.25
ME	0.43	0.00
MI	5.17	0.01
MN	0.42	0.01
MO	1.35	8.14
MS	0.91	0.27
MT	0.00	0.00
NC	4.04	0.00
ND	0.02	0.00
NE	0.09	0.00
NH	0.56	0.10
NJ	5.43	0.50
NM	0.01	0.00
NV	0.00	0.00
NY	11.41	0.75
OH	10.16	24.34
OK	0.29	0.00
OR	0.00	0.00
PA	10.87	4.19
RI	0.46	0.00
SC	1.55	0.00
SD	0.03	0.00
TN	3.46	12.61
TX	1.21	0.00
UT	0.01	0.00
VA	4.82	0.00
VT	0.27	0.00
WA	0.00	0.00
WI	1.15	0.67
WV	2.04	9.92
WY	0.00	0.00

Table 4B – Cross-State Distribution of Benefits and Costs ($1995 per capita)

	Scenario 1			Scenario 2		
State	Benefit	Cost	Net	Benefit	Cost	Net
AL	276.5	2.1	274.4	23.4	0.4	23.0
AR	125.3	0.0	125.3	16.8	0.0	16.8
AZ	0.8	0.0	0.8	0.1	0.0	0.1
CA	0.2	0.0	0.2	0.1	0.0	0.1
CO	7.9	0.0	7.9	-0.3	0.0	-0.3
CT	295.6	0.0	295.6	-21.6	0.0	-21.6
DC	529.4	0.0	529.4	-12.4	0.0	-12.4
DE	446.6	0.0	446.6	-26.1	0.0	-26.1
FL	121.1	1.5	119.6	-21.5	-0.4	-21.1
GA	284.6	4.7	279.9	25.2	1.7	23.5
IA	83.4	0.0	83.4	6.8	0.0	6.8
ID	1.0	0.0	1.0	0.0	0.0	0.0
IL	219.9	2.9	217.0	12.4	1.5	10.9
IN	442.2	13.1	429.1	-4.7	-10.2	5.4
KS	43.3	0.0	43.3	2.8	0.0	2.8
KY	458.8	8.6	450.2	-29.6	-4.5	-25.2
LA	95.2	0.0	95.2	9.8	0.0	9.8
MA	246.8	0.1	246.7	-16.1	0.1	-16.2
MD	535.4	1.4	534.0	-23.0	-0.5	-22.5
ME	191.0	0.0	191.0	-14.5	0.0	-14.5
MI	300.8	0.0	300.8	1.9	0.1	1.8
MN	50.7	0.0	50.7	7.0	0.2	6.8
MO	141.2	8.5	132.7	39.4	2.6	36.7
MS	188.7	0.5	188.1	24.8	-0.1	24.9
MT	2.3	0.0	2.3	0.0	0.0	0.0
NC	307.9	0.0	307.9	4.7	0.0	4.7
ND	14.4	0.0	14.4	0.4	0.0	0.4
NE	31.9	0.0	31.9	2.4	0.0	2.4
NH	265.5	0.5	265.0	-49.0	-1.2	-47.8
NJ	376.2	0.3	375.9	-29.8	-0.5	-29.3
NM	4.7	0.0	4.7	0.5	0.0	0.5
NV	0.6	0.0	0.6	0.1	0.0	0.1
NY	345.3	0.2	345.1	-25.9	0.3	-26.3
OH	511.8	12.2	499.6	-27.5	-3.6	-23.9
OK	48.6	0.0	48.6	4.9	0.0	4.9
OR	0.1	0.0	0.1	0.0	0.0	0.0
PA	503.5	1.9	501.5	-38.2	0.2	-38.4
RI	250.3	0.0	250.3	-15.5	0.0	-15.5
SC	231.2	0.0	231.2	13.6	0.0	13.6
SD	22.6	0.0	22.6	1.4	0.0	1.4
TN	366.1	13.3	352.8	11.1	2.3	8.8
TX	35.9	0.0	35.9	3.6	0.0	3.6
UT	1.8	0.0	1.8	-0.0	0.0	-0.0
VA	450.7	0.0	450.7	-7.9	0.0	-7.9
VT	261.6	0.0	261.6	-16.5	0.0	-16.5
WA	0.2	0.0	0.2	0.0	0.0	0.0
WI	125.9	0.7	125.2	8.5	0.6	7.9
WV	632.6	30.8	601.8	-5.1	-20.3	15.1
WY	5.0	0.0	5.0	0.0	0.0	0.0

Table 5A -- Benefits and Costs Across Different Populations (Scenario 1; average per capita $1995)

DEMOGRAPHIC GROUP	BENEFITS	COSTS	NET BENEFITS
TOTAL	213.1	2.1	211.0
BLACKS	253.6	2.1	251.5
HISPANICS	102.0	0.6	101.4
POOR	202.8	2.2	200.6
KIDS	204.9	2.0	202.9
ELDERLY	220.8	2.2	218.6

Table 5B -- Benefit/Cost Ratio Across Different Populations (Scenario 1)

DEMOGRAPHIC GROUP	Benefits/Costs
TOTAL	100
BLACKS	121
HISPANICS	180
POOR	93
KIDS	100
ELDERLY	99

Table 6 – Distribution of Benefits and Costs Across Different Populations (Scenario 1; % of Plants with Cost Share>Benefit Share)

DEMOGRAPHIC GROUP	Cost Share>Benefit Share
BLACK	25%
HISPANIC	10%
POOR	48%
KIDS (6 and under)	52%
ELDERLY (65 and older)	43%

Table 7 – Distribution of Benefits per Ton Reduction Across Plants

Distribution	Benefits/Ton
Maximum	$35,868
90%	$19,662
75%	$17,477
50%	$15,414
25%	$12,575
10%	$9,601
Minimum	$3,763

Table 7A – Distribution of Benefits per Ton Reduction
For Permit Buyers and Sellers

	Low Benefits (<$12,500)	Middle Benefits ($12,500-$17,500)	High Benefits (>$17,500)
Permit Buyers	**2**	**14**	**14**
Permit Sellers	**22**	**44**	**14**

States with predominantly high-benefit plants: PA
States with predominantly low-benefit plants: AL, FL, GA, MS

Figure 1
Distribution of Plants in Database
(148 Plants; scale=1995 SO_2 emissions in tons)

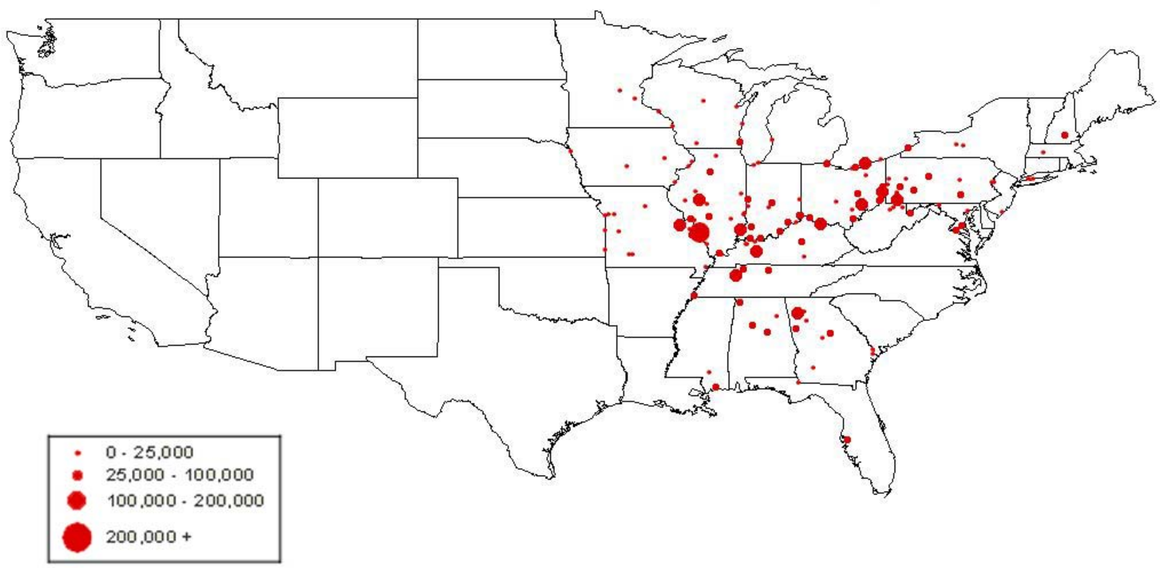


Figure 2
Geographic Distribution of Benefits
Scenario 1

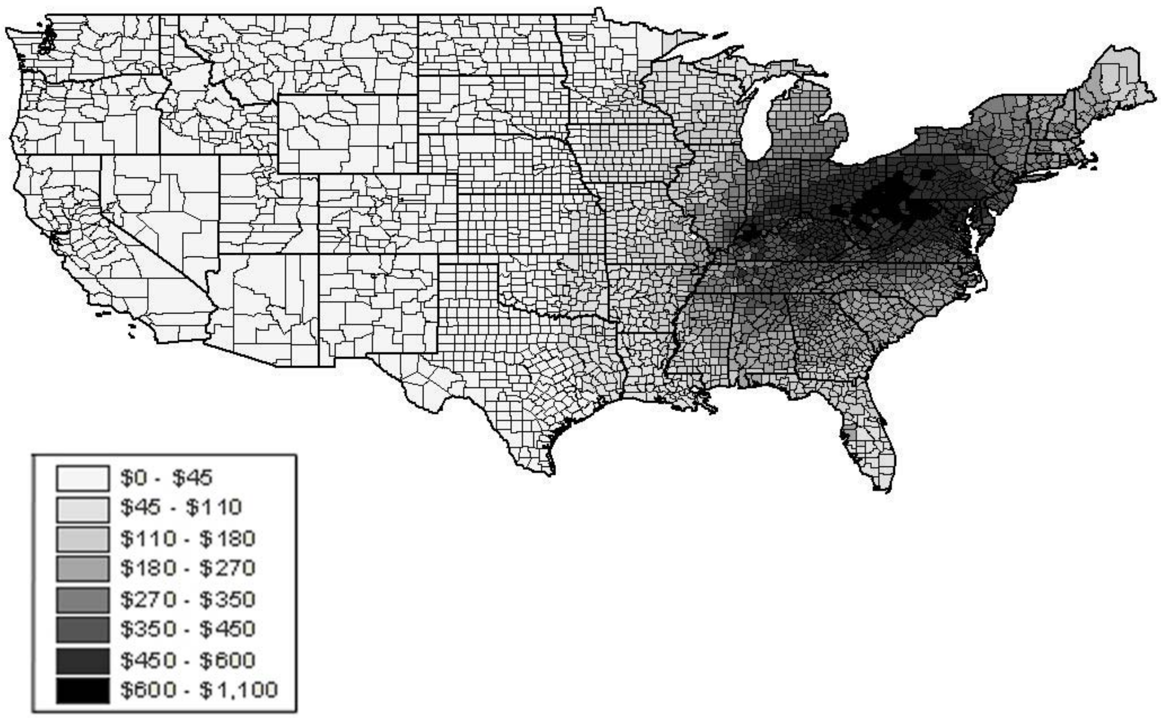
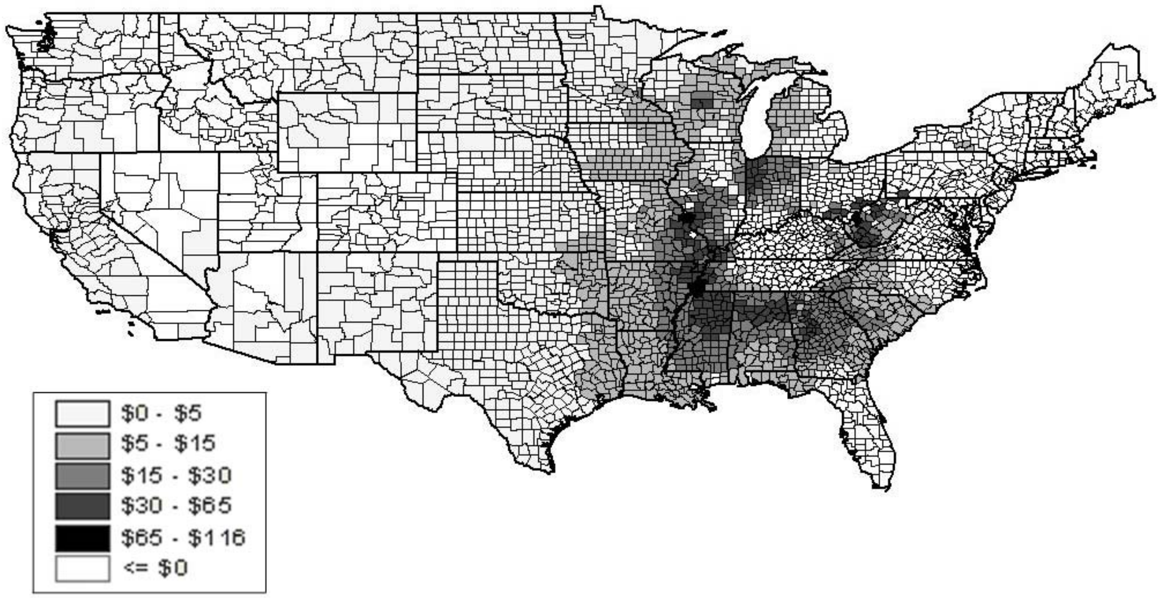


Figure 3
Geographic Distribution of Benefits
Scenario 2

Net Winners



Net Losers