Uncertainty and the Cost-Effectiveness of Regional NO_X Emissions Reductions from Electricity Generation

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Abstract

This paper analyzes uncertainties surrounding the benefits and costs of a policy to reduce nitrogen oxides (NO_X) emissions from electricity generation in the eastern United States. Under each of 18 scenarios examined, we find an annual policy would yield net benefits that are at least as great as those expected under the U.S. Environmental Protection Agency's (EPA) currently planned seasonal policy. Preferred (midpoint) assumptions yield additional benefits of $724 million per year under an annual policy compared to a seasonal one (1997 dollars). The subset of 11 northeastern states benefit the most from an annual policy relative to a seasonal one, but relative net benefits are also positive in the remaining states in the region. An annual policy implemented on a national basis appears to be slightly less cost-effective than the EPA's policy under midpoint assumptions but it is more cost-effective under half of the scenarios we examine.

Key Words: emissions trading, electricity, particulates, nitrogen oxides, NO_X, health benefits, market structure, restructuring, deregulation, value of statistical life, uncertainty

JEL Classification Numbers: Q2, Q4

Executive Summary

Emissions of NO_X contribute to high concentrations of atmospheric ozone that are associated with human health hazards. This has led the U.S. Environmental Protection Agency (EPA) to call on 19 eastern states, where the problem is most pronounced, to reformulate state implementation plans (SIPs) for reducing NO_X emissions. This paper analyzes policies to reduce nitrogen oxide (NO_X) emissions from electricity generation in the United States under various scenarios in which the magnitude of benefits and costs are uncertain. The analysis considers three NO_X reduction policies: a summer seasonal cap in the eastern states covered by EPA's NO_X SIP Call, an annual cap in the same SIP Call region, and a national annual cap. All policies allow for emissions trading. Net benefits (benefits less costs) are calculated on the basis of particulate-related health effects and the cost of post combustion controls.

For each of the three policies, we consider 18 scenarios, reflecting the range of prominent and plausible parameter values for three primary sources of uncertainty. One source of uncertainty is the future structure of the electricity market, for which we consider two possibilities—limited restructuring and nationwide restructuring—to capture the range of uncertainty surrounding NO_x emissions levels from the electricity sector in the absence of an emissions policy. A second source of uncertainty is the epidemiological relationship between nitrates and premature mortality. From the epidemiological literature we choose a low, mid, and high value for the concentration-response (C-R) coefficient. The range of the C-R coefficient represents uncertainty pertaining to the mortality effects of nitrates. The third source of uncertainty is the economic valuation of premature mortality. From the economics literature we choose a low, mid, and high value for the value of a statistical life (VSL).

Under all scenarios examined, we find an annual cap in the SIP Call region yields net benefits that are at least as great as those expected under EPA's current plan to implement a seasonal cap. The preferred (midpoint) assumptions lead to additional net benefits of $724 million per year under an annual policy compared to a seasonal one, but among all the scenarios, additional net benefits of an annual policy range from $0 to $3 billion per year (1997 dollars).

The distribution of the net benefits is not uniform within the SIP region. The subset of the SIP region that includes 11 northeastern states benefits the most under the SIP annual policy relative to SIP seasonal, and the remaining eight states in the SIP region would benefit the least, but under no scenario are the remaining eight states worse off due to the shift to the SIP annual policy.

The seasonal policy is preferable by only a small amount to a national annual cap under preferred assumptions for uncertain parameters. However, the national annual policy is preferable in half of the scenarios we examine. Within the SIP Call region, a national annual policy would yield greater net benefits than either regional policy due to the reduction in atmospheric transport of pollutants from outside the region that occurs under a national policy. However, under such a policy net benefits outside the SIP Call region would not be favorable, at least when measured on the basis of particulate matter (PM)-health benefits alone.

Consideration of omitted benefits, such as reduced nitrogen deposition and ozone, would strengthen the finding that an annual policy in the SIP Call region is more cost-effective than a seasonal policy. However, omitted benefits could play an important role when comparing a regional policy with a national policy, since the relative cost-effectiveness of the national annual policy is sensitive to the assumptions in the scenarios we model. Benefits from reduced ozone concentrations may be especially important, since in many western states the ozone season stretches beyond the five summer months that are relevant in the east. It is also possible that benefits from reduced nitrogen deposition are important, though there currently is an incomplete understanding of the ecological effects.

As the states move toward competition in the electricity sector, the net benefits of all of the policies tend to be systematically higher than when under regulation. However, the relative cost-effectiveness of the policies does not appear to be sensitive to the future structure of the electricity industry.

In summary, we find strong evidence that EPA and the affected states should consider replacing the current initiative for the eastern United States—a seasonal program to reduce NO_X emissions—with a new initiative aimed at annual reductions in the region. Further research and policy discussions addressing annual national standards are also warranted.

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1. Introduction

The U.S. electric power sector is the focus of potentially far-reaching legislative and regulatory efforts to reduce emissions. The next big set of reductions is likely to occur with the implementation in 2004 of a regional summertime cap and trade program for nitrogen oxides (NO_X). The current Environmental Protection Agency (EPA) plan would affect 19 eastern states plus the District of Columbia, and is motivated primarily by concerns about high summertime concentrations of harmful ground-level ozone in eastern U.S. cities, of which NO_X emissions are precursors. The policy is known as the "SIP Call" because it calls for states to revise their state implementation plans (SIPs) for compliance with federal Clean Air Act goals. The program will require electricity generators throughout the East to reduce their average summertime NO_X emission rate to about 0.15 pounds per million Btu (MMBtu) of heat input at fossil fuel–fired boilers, leading to a reduction of 62% in summertime emissions in 2007 according to EPA estimates.[1] The requirement is coupled with a regional cap and trade program similar to that which is currently in place for SO_2 emissions, and for NO_X emissions in a subset of the affected states.

The SIP Call program would achieve important ozone reductions. However, as currently planned, the program ignores perhaps more important reductions of particulate matter (PM), as well as nitrogen deposition in ecosystems, that would accompany reductions in NO_X. Whereas benefits from reducing ozone occur almost exclusively in the summer, the other benefits would be realized throughout the year. When reduced

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[1] The five-month summer emissions cap under this program is based on an average NOx emission rate of about 0.15 pound per million Btu's of heat input at fossil fuel–fired boilers. The program would lead to annual reductions in NOx emissions of 22% by 2007 and summertime reductions of 40% in the same year (U.S. EPA 1998a.). In the SIP Call region, the program would reduce NOx emissions by 40% annually in 2007 and by 62% in the summers (U.S. EPA 1998b, Table 2-1).

particulate concentrations and other benefits of reductions in NO_X emissions are taken into account, an alternative policy design may emerge as more cost-effective.

Recent papers and proposals have highlighted potential alternatives to the planned seasonal SIP Call program. Burtraw et al. (2001) conducted a cost-effectiveness analysis that compared the seasonal program with both an annual cap-and-trade program in the SIP Call region, as well as an annual national program. The study concluded that an annual program in the SIP Call region would be the most cost-effective approach when benefits from reduced concentrations of PM plus additional costs were taken into account. The annual program in the SIP region would yield more than $400 million per year (1997 dollars) in additional net benefits (benefits minus costs) compared to a seasonal program based only on health effects. However, the paper does not find a justification for extending the program geographically to cover the entire nation.

Palmer et al. (2001a) examine just two policy options, seasonal and annual programs in the SIP Call region. However, that paper considered two possible structures for the electricity market, and found a substantial difference in cost-effectiveness as a result of market structure. Compared to the current mix of regulation and competition, nationwide competition in the electricity industry would increase emissions in the absence of a NO_X policy. Therefore, achieving an emission cap under the policies would yield greater health benefits but also entail greater costs. In sum, under nationwide competition, an annual program would yield $770 million (1997 dollars) in additional net benefits compared to a seasonal program.

In addition to these simulation studies, some advocates have called for a re-examination of the program in favor of annual controls on NO_X emissions (Gutt et al., 2000). Annual controls also have become the focus of proposed legislation at the federal level.

Results from the previous analyses have been couched in an acknowledgement that there exists tremendous uncertainty about various aspects of the integrated models that are used, though they have not accounted in a systematic way for sources of uncertainty. In addition, the assumptions used to parameterize the earlier exercises are controversial because of uncertainty surrounding key aspects of the assessment. The omission of an analysis of uncertainty is not without consequence because alternative realizations of uncertain variables might either reinforce or alter the suggested ordering of policies from a cost-effectiveness perspective.

This paper re-examines the set of policies that have been considered previously and identifies the major sources of uncertainty in the analyses that could contribute to different conclusions. Previous literature leads us to focus in detail on three issues. One is the characterization of the electricity market structure in the future, and associated projections of emissions in the absence of a policy. Palmer et al. (2001a) considered alternative realizations for the industry, but not in combination with any other potential sources of uncertainty and not for all of the policies we consider.

A second source of uncertainty is the characterization of the epidemiology of premature mortality in response to changes in atmospheric concentrations of pollutants. A three-fold difference in this response can be reasonably explored, based on the existing literature. This translates directly into a three-fold difference in mortality-related health benefits, which are the largest share of estimated benefits. A third source of uncertainty is the economic valuation of small changes in the risk of premature mortality. Again, the literature suggests that nearly a three-fold range of values can be reasonably assumed, translating directly into a three-fold difference in mortality-related health benefits. Considered in combination, the uncertainties surrounding these three questions can lead to an order of magnitude difference in expected mortality-related benefits of reductions in NO_X, an important difference in the measure of costs, and dramatic changes in the relative cost-effectiveness of the policies.

We consider three NO_X reduction scenarios mentioned previously in light of these uncertainties. The policies include a summer seasonal cap in the eastern states covered by EPA's NO_X SIP Call, an annual cap in the same SIP Call region, and a national annual cap. The uncertainties include two possible outcomes for market structure, three possible interpretations of the epidemiology, and three possible interpretations of the valuation literature, making for 18 scenarios in total. We estimate net benefits for each of the three policy options under the 18 possible realizations of the uncertain factors. Net benefits include particulate-health related effects of NO_X, and exclude the effects of ozone on health and other particulate-related benefits. Cost is measured as the annualized capital and operating cost of post-combustion controls.

Two clear conclusions emerge from the analysis. The first is that, in every scenario, an annual cap in the SIP Call region yields net benefits (benefits less costs) that are at least as great as those expected under the EPA's current policy to implement a seasonal cap. The additional net benefits of an annual policy range from $0 to $3.7 billion (1997 dollars); under our preferred assumptions, net benefits improve by $724 million compared to the current seasonal policy. The consideration of omitted benefits from this accounting strengthens the relative cost-effectiveness of an annual policy in the SIP Call region compared to the current seasonal approach. This provides compelling evidence in support of previous suggestions that the EPA and the affected states should consider annual policies in place of the seasonal policy currently envisioned under the NO_X SIP Call.

The second conclusion is that the relative cost-effectiveness of a national annual policy sits on a knife-edge with respect to each of the uncertainties. The seasonal policy is slightly preferable to a national annual cap under preferred (midpoint) values for uncertain parameters. An annual policy at the national level would yield greater net benefits to the SIP Call region than either an annual or seasonal policy in that region due to the reduction in atmospheric transport of pollutants from outside the region. Net benefits outside the region under a national policy would not be favorable, at least when measured solely on the basis of PM-health benefits. However, if any of the three uncertain parameters realize high-end values relative to our original preferred assumptions, the national annual cap could be preferable to a seasonal policy after taking into account the benefits we do not measure. Thus, additional information about the magnitude of omitted benefits is important to determining the relative cost-effectiveness of a national policy.

2. Previous Literature and Major Sources of Uncertainty

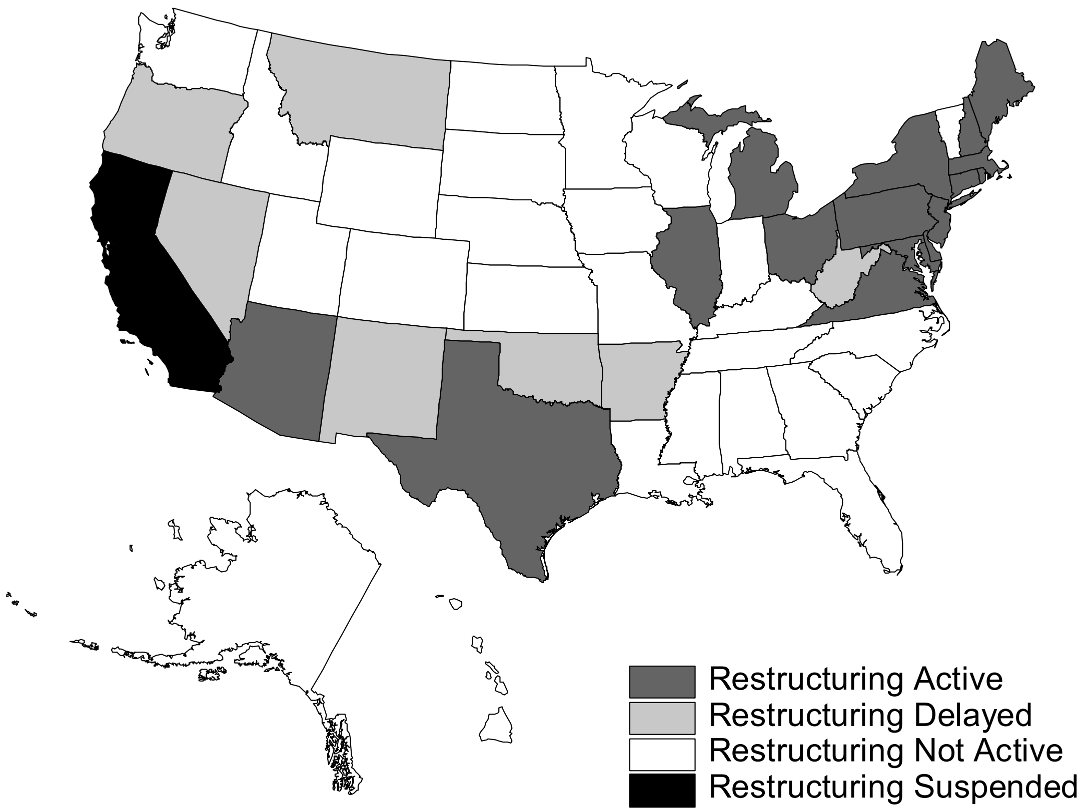
The analysis we conduct integrates models of the electricity sector, pollution transport, health epidemiology, and valuation. In this framework, we identify three questions as the most important sources of uncertainty. These include the structure of the electricity market (i.e., whether the nation as a whole follows the lead of states that have already committed to competition in the electricity sector), the epidemiological characterization of mortality effects due to changes in concentrations of nitrates, and the valuation of changes in health status. In this section, we describe these uncertainties and why they are expected to be most important.

2.1 Structure of the Electricity Market

The passage of the Energy Policy Act of 1992 unleashed a process that is changing the regulatory and market structure of the U.S. electric power industry. The act called on the Federal Energy Regulatory Commission to order all transmission-owning utilities to allow open access to their transmission systems at nondiscriminatory, cost-based transmission rates in order to facilitate competitive wholesale power transactions. At this time, 24 states plus the District of Columbia have passed legislation or made regulatory decisions to allow retail competition, as illustrated in the map in Figure 1. However, the timing varies among the states. Several states, including West Virginia and Oklahoma, have a long timeframe for implementation. Other states, including Oregon, Nevada, and New Mexico, have slowed their progress, and California has backed away from retail choice.

An important question throughout the debate about electricity restructuring is how the move from regulation to competition will affect the environment. Many advocates have raised concerns that allowing more open access to transmission would lead to the increased use of older, dirtier coal-fired facilities in the Midwest and related increases in emissions. As different states debated whether to allow retail competition, some observers became concerned about the potential demise of utility programs that promoted demand-side management and the use of renewable energy sources, as well as the associated consequences for utility emissions and the environment. In addition, if restructuring were to deliver the lower prices for electricity as is expected, then increased levels of electricity demand could also yield higher emissions.

Figure 1 Status of restructuring as of November 2001. Source: U.S. Energy Information Administration, Nov. 2001 (www.eia.doe.gov/cneaf/electricity/chg_str/regmap.html).



Several previous studies, including those by Lee and Darani (1996), the Center for Clean Air Policy (1996a, 1996b, 1996c), and Rosen and others (1995), find potentially large increases in emissions of NO_X and CO_2 would result from increased interregional power trading. In two analyses of the proposed environmental impacts of its two transmission orders, U.S. FERC (1996, 1999) finds increased power trading has a much more limited effect on air emissions. EIA (1996) also finds that open transmission access increases NO_X emissions to between 1% and 3% above the baseline scenario, with the largest effects happening in the early years.

Palmer and Burtraw (1997) look at the potential impacts of electricity restructuring on NO_X and CO_2 emissions and on subsequent changes in atmospheric NO_X and nitrate concentrations at the regional level, and also consider the ultimate effect on human health. Their results concerning emissions effects fall roughly in the middle of the estimates from the prior literature. Burtraw, Palmer, and Paul (1999) find electricity restructuring has substantially smaller impacts on NO_X and CO_2 emissions in the near term, with NO_X emissions increases of 4% or less relative to the baseline and annual carbon emission increases of just under 2% in the absence of any policy to promote renewable energy sources. U.S. DOE (1999) looks at the emissions effects of the Clinton administration's Comprehensive Electricity Competition Act of 1999 and demonstrates that the act, with its provisions to promote greater use of renewables and distributed generation, would have led to a reduction in NO_X and carbon emissions compared with an average cost baseline.

Most of the prior analyses of the effect of restructuring on emissions ignored the effect of EPA's 1998 NO_X SIP Call on summer NO_X emissions from electricity generators in the eastern United States. By imposing summertime caps on NO_X emissions that apply to both new and existing generating facilities, this program eliminates the possibility of increasing aggregate summertime NO_X emissions in the SIP Call region as a result of restructuring.

Nonetheless, NO_X emissions during other seasons and in other regions could rise as a result of increased power trading or increased generation to meet higher levels of demand brought about by anticipated lower prices under competition. These additional NO_X emissions could contribute to higher concentrations of particulate matter, which have been firmly associated with morbidity and mortality effects. In addition, NO_X emissions cause the deposition of nitrates, which contribute to environmental problems such as the acidification of some ecosystems. If NO_X emissions from electricity generators were subject to an annual cap, then restructuring would have no effect on aggregate NO_X emissions. In response to the potential for increased emissions from restructuring, and also in response to the regional and seasonal nature of the EPA's SIP Call, environmentalists have proposed expanding the NO_X SIP Call to an annual program (Gutt, 2000).

Uncertainty about the structure of the market has an influence on the cost of emission reductions, though the direction is not immediately obvious. The cost savings associated with technical improvements may offset some of the costs of greater NO_X

controls, or introduce additional flexibility in compliance due to greater flexibility in the operation of generators, thereby lowering costs. Alternatively, efficiency improvements at existing coal plants could raise the value of the plants and raise the opportunity costs of substituting away from using these plants toward lower polluting plants. This change would raise the costs of reducing NO_X emissions. Further, nationwide adoption of retail competition could generate greater inter-regional trading of electricity, particularly if widespread restructuring leads to expansion of inter-regional transmission capability as assumed in the scenarios modeled here. For example, with greater transmission capacity, electricity generation could migrate out of the SIP Call region helping to reduce NO_X emissions in the region and potentially lower the costs of achieving the NO_X emission caps, but increasing emissions in the West.

Two recent papers have analyzed emission scenarios that take into account the performance of the NO_X SIP Call under alternative market structures. Using the modeling framework we use in this paper, Burtraw and others (2001) analyze “limited restructuring.” The analysis assumes that no states move to implement electricity restructuring beyond those that had made a decision as of 2000. That paper considered seasonal and annual NO_X policies in the SIP Call region as well as a national annual NO_X policy. A contrasting paper that uses the same modeling framework by Palmer and others (2001a) examined “nationwide restructuring,” but that paper considers only seasonal and annual NO_X policies in the SIP Call region. Palmer and others find the movement to marginal cost pricing leads to an increase in electricity generation, much of which comes from existing coal-fired power plants. In the absence of a NO_X cap, they find restructuring would lead to an annual increase of 369,000 tons of NO_X (8%) in 2008. Even when restructuring is combined with a NO_X policy in the SIP Call region, restructuring leads to greater quantities of NO_X outside the region.[2]

These two papers indicate that uncertainty about the structure of the market may have an effect on the distribution of NO_X control costs born by producers and by

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[2] A related source of uncertainty is the assumption about future fuel prices. However, if natural gas supplies become limited, either due to natural availability or regulatory decisionmaking, then we would expect to see more coal-fired generation in both the baseline and in the policy cases we model. The result would be somewhat closer to the scenario involving the effects of marginal cost pricing in the electricity sector.

consumers. One reason is that whether the opportunity cost of emission allowances are reflected in electricity price depends on how allowances are allocated and whether a state is regulated. We assume allowances are allocated to firms at zero cost—so-called "grandfathering"—as currently intended by most states planning to participate in the NO_X trading program and as characterized the SO_2 trading program implemented under the 1990 Clean Air Act amendments. In average cost regions, emission allowances are reflected in the calculation of total costs according to their original cost when acquired by the firm. Because the original allocation was at zero cost, only the costs of allowances acquired in excess of the original allocation are considered part of the total costs to be recovered in the price of electricity. In marginal-cost regions, the opportunity cost of NO_X emissions allowances is reflected in the electricity price in a manner analogous to other variable costs of generation, such as fuel costs. In this case, NO_X emission allowances are reflected in marginal costs to the extent that the marginal generating unit at any particular instant requires allowances to generate. When the marginal generating unit is coal-fired, the cost of NO_X emissions allowances is fully reflected in the price of electricity paid by consumers. When the marginal generating unit is gas-fired, the cost of NO_X emissions allowances will play a smaller role in the price of electricity because gas-fired units typically have lower emissions per unit of generation, and producers will bear more of the cost of the NO_X policy.

2.2 Epidemiology

Although there is substantial evidence that contribution to the global nitrogen cycle has significant ecological effects, the effect of nitrogen oxides and nitrates on human health is by far the most important of the problems that have been quantified in previous analysis (Lee et al.,1995; Hagler Bailly, 1995; European Commission, 1995). Analysis of the uncertainties surrounding estimates of benefits and costs of changes in conventional pollutants identified mortality as the environmental problem that would most benefit from additional research (Burtraw et al., 1998). We focus specifically on the uncertainty pertaining to the mortality pathway, which breaks down into two areas: epidemiology and valuation.

There are several sources of uncertainty that surface in the epidemiological literature. First, there is considerable uncertainty as to the shape of the concentration-response (C-R) function, and the presence or absence of a threshold level of pollutant concentration, below which there are no significant health effects observed. Traditionally, a linear model has been assumed for both ease of modeling and interpretation, as well as for the fact that the data has tended to fit such a model reasonably well. The common C-R function is thus of the following form:

$$\Delta M = C \times MortalityRate \times Pop \times \Delta PM10,$$

where *M* is the number of annual deaths, *C* is the C-R coefficient, representing a percentage change in the mortality rate (deaths per person per year) for a given change in PM10 concentration. *Pop* is the exposed population, and PM10 is measured in $\mu g/m^3$.

While both the questions of functional form and the existence of a threshold have been debated in the literature, the case for a linear model with no threshold is strong. Most recently, a study by Daniels et al. (2000) suggests that linear models without a threshold are preferable for assessing the effect of particulate air pollution on both total mortality and respiratory/cardiovascular mortality at current levels.

A second source of uncertainty is the problem of distinguishing between acute and chronic mortality, and the implications of doing so for the estimation of a C-R relationship. There is a considerable body of literature estimating acute mortality effects of air pollution. These studies use daily time series data to estimate the relationship between short-term changes in PM and daily death counts. In general, these studies have suggested an increase in the daily mortality rate ranging from less than 0.5%-1.5%, with lagged pollution effects of up to five days, though generally closer to one. A major criticism of these time series studies is that, by only reporting associations between daily mortality rates and pollution levels, they are unable to estimate the degree to which the excess mortality observed is due to mortality displacement—the amount of the excess mortality measure that is attributed to individuals of compromised health status with short life expectancies in the absence of pollution. This criticism has important implications for the valuation of mortality effects.[3]

Studies of chronic mortality, or prospective cohort studies, have estimated changes in mortality rates due to long-term trends in air pollution concentrations.[4] Prospective studies track a group of individuals through time for a specified period, periodically monitoring the exposure of individuals and their health status. The C-R coefficients from the prospective studies have tended to be substantially larger than those from acute mortality studies, estimating an increase in the daily mortality rate of 3% or greater per 10 μg/m3 increase in particulate matter less than 10 microns in diameter (PM10). Of the handful of such studies that exist, Pope et al. (1995) is considered to be the most robust, for its large cohort (more than 295,000) and number of observed locations (50) in the study for particulate matter. However, Dockery et al. (1993) has been criticized for examining an inadequate number of locations, and the cohort in Abbey et al. (1993) has been criticized as being too small to yield reliable results.

Addressing the differences in results between these two methodologies is complicated by the fact that the biological mechanism by which particulate matter affects human health remains elusive. Furthermore, there are additional sources of uncertainty surrounding the parameter estimates from both types of studies. First, there is the potential error that results from using ambient particulate matter concentrations as a proxy for personal exposure levels. Second, there is the question of confounding from other pollutants or other potential risk factors. An inability to sufficiently control for such factors in analysis will result in potentially biased C-R coefficients. Among these potential risk factors are a number of socioeconomic, occupational, and weather variables. While prospective cohort studies have the ability to control for obvious individual risk factors, such as cigarette smoking, there is still a possibility of inadequate control of other risk factors and variables of this type.

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[3] In studies where mortality benefits are estimated in terms of life-years lost, the presence of significant mortality displacement, assuming it could be accounted for, would dramatically reduce benefit estimates.

[4] Another group of studies of chronic mortality are ecologic studies, such as Lipfert (1994) and Ozkaynak and Thurston (1987), which correlate location-specific mortality rates with measures of pollutant concentration in each location. However, these studies are typically dismissed as being unable to control for individual differences in risk factors, such as smoking behavior.

Further uncertainties result from issues of potential measurement error. There is considerable uncertainty regarding the composure and uniformity of particulate matter. Epidemiological studies focus on a specific measure of particulate matter, typically total suspended particulates (TSP), or PM10 or PM2.5 (particulate matter less than 2.5 microns in diameter), with mortality being believed to be more closely associated with smaller particles. However, studies of health benefits might use a C-R coefficient for one particle size to estimate health benefits from reductions of a particle size that is either larger or smaller. Doing so introduces uncertainty, in that converting C-R coefficients to represent another particle size requires assuming these particulate measures exist in constant proportion, an assumption that is unlikely to hold either temporally or spatially.

Finally, there is additional uncertainty pertaining to the application of a selected C-R coefficient, which is often being estimated for one city or a subset of the population not representative of all socioeconomic groups, to the population at large. Schwartz and Dockery (1992), for example, examine mortality only in the locality of Steubenville, Ohio. Recent work by Samet et al. (2000) suggests that response to changes in PM concentration may vary significantly by region, with effects in the northeast being most sensitive. Furthermore, Krewski et al. (2000) find evidence that C-R coefficients for PM vary significantly by education level, with risk decreasing at higher levels of educational attainment. Likewise, Pope et al. (1995) has been criticized for following a largely white and middle class population, potentially producing a downward bias in the coefficient. As methodologies improve, and such findings are corroborated by additional research, health effects estimates based on the epidemiological literature will be able to increasingly utilize such information.

2.3 Valuation of Changes in Risk of Premature Mortality

The second parameter that contributes importantly to the uncertainty along the air-health environmental pathway is the valuation of changes in the risk of premature mortality. Typically, this parameter is described as the value of a statistical life (VSL). Precisely, the parameter represents the willingness of a representative individual to pay to avoid small changes in risk. This value is divided by the magnitude of the change in risk and the result is the estimated VSL.[5] Since the VSL is the last parameter in the pathway linking changes in emissions to the estimate of benefits (B), the estimate varies directly with the VSL according to the function: $B = VSL \times \Delta M$. The estimates of VSL that are found in the economic literature vary by more than an order of magnitude, but meta-analyses and most studies identify a range that varies by a factor of three, from about \$2 million to about \$6 million (1997 dollars). [6]

The preferred estimates of the VSL are derived using willingness-to-pay (WTP) estimates, which are obtained primarily through two methodologies. The first is hedonic labor market studies, which employ revealed preference techniques by relating wage differentials to mortality risk differences across industrial or commercial sectors. The underlying assumption behind these studies is, given competitive labor markets, workers in occupations with inherent risk should receive wage premiums equal to the value they place on increased mortality risk. There are a number of uncertainties specific to the WTP estimates obtained in these studies. First, there is not complete agreement in the literature as to the existence of a statistically significant relationship between the risk of death on the job and wage. While the majority of studies do find such a relationship, Mrozek and Taylor (2002) report there are at least 16 that do not. Among these are Moore and Viscusi (1988), Leigh (1991 and 1995), and Dorman and Hagstrom (1998). Second, specification of the hedonic wage equation can vary considerably, within and among studies, leading to substantial variation in WTP estimates. It is likely that misspecification of the wage equation —particularly inadequate control of inter-industry wage differentials—as well as imprecise measurements of risk are the primary factors contributing to both the controversy over the wage-risk relationship and the variation in WTP estimates (Leigh, 1995; Dorman and Hagstrom, 1998; Mrozek and Taylor, 2002)

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[5] For example, if each individual in a population is willing to pay \$50 for a mortality risk reduction of 1/100,000, the implied VSL is \$50 x 100,000=\$5 million.

[6] An alternative to using a VSL is the value of a statistical life-year (VSLY), which is typically an annualized equivalent of a VSL estimate (Moore and Viscusi 1988) obtained by dividing a VSL estimate by the average life-expectancy of individuals within the study population. It is also typically assumed that the individual discounts the value of future years. Two shortcomings of this approach are the assumption that the VSLY is independent of age, and the sensitivity of benefits estimates to the assumed discount rate, which is usually chosen somewhat arbitrarily by the researcher.

Application of VSL estimates to the valuation of premature mortality effects raises several uncertainties pertaining to the issue of benefits transfer. For one, the degree of mortality risk reduction for which WTP estimates are elicited in a given study may not correspond to the degree of mortality risk reduction for which benefits are being estimated. The transfer of a given WTP estimate to a benefit analysis implicitly assumes a linear relationship between mortality risk reduction and WTP. Rowlatt et al. (1998) suggest this is a reasonable assumption, provided the change in the risk being valued is within the range of risk evaluated in the studies underlying the assumed VSL.

Furthermore, transferability depends upon the extent to which the population and risk in the study are comparable to the population affected and the risk that they face. For example, epidemiological literature provides some evidence that excess mortality from particulate matter may disproportionately affect the elderly. The elderly, however, have not been adequately represented in most studies estimating WTP. In particular, labor market studies typically have measured compensation received by prime-aged working men for mortality risk. One might expect the elderly to have a lower WTP to avoid small changes in risk, given their shorter life expectancy.[7] In addition, job-related risks are typically incurred voluntarily, whereas air pollution risks are involuntary. There is some evidence that individuals have higher willingness to pay for the reduction of involuntary risks than for reduction of risks incurred voluntarily.[8] Recently, the criticisms of revealed preference labor market studies have led to the increased use of stated preference (typically contingent valuation) techniques to value mortality risk reductions. Contingent valuation (CV) studies ask individuals to value a given reduction in mortality. These studies might be preferred to hedonic labor market studies because they have the potential to appropriately characterize the mortality risk of interest. Individuals can be made aware that the risk is involuntary, can be told the specific nature of the risk reduction, and can be tested on their understanding of the risk. In addition, CV allows for the testing of hypotheses that WTP varies by individual factors, such as age or health status.

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[7] Krupnick et al. (2000) find that age is associated with WTP, observing a reduction in WTP for ages 70 and above.

[8] See, for example, Violette and Chesnut (1983).

The ability to test for correct risk perception is an important advantage of CV studies over revealed preference labor market studies, which must assume correct perception of risk by study subjects. When risk is perceived correctly, WTP should increase with the size of risk reduction, a notion that can be tested for sensitivity to "scope"—that is, whether the WTP is sensitive to the extent of the risk reduction. However, a literature review by Hammitt and Graham (1999) provides evidence that few CV studies of mortality risk actually pass such tests. In Jones-Lee et al. (1985), and Smith and Desvouges (1987), for example, WTP does not increase at all with the size of risk change.

Two recent studies explicitly attempt to match the nature of injury from PM to WTP for a reduction in PM exposure. Krupnick et al. (2002) and Alberini et al. (2001) indicate lower estimates of the VSL than are being used by EPA. These results are explained by a better communication to subjects of the concepts of both probability of the effect among the population in the study, and the future health status of individuals, as compared to populations in previous studies. Interestingly, the lower estimates do not result from either differences in health status or age among the population. New territory for future studies exists in the incorporation of the effects of more abstract characteristics of risk, such as dread or the lack of controllability.

2.4 Other Sources of Uncertainty

Other sources of uncertainty that we do not examine explicitly in this paper include the physical and chemical transformation of NO_X emissions in the atmosphere and its transport, the cost of the emission trading program, and the parameters in the electricity market equilibrium model (Haiku) that characterize restructuring.

The physical and chemical transformations of NO_X emissions in the atmosphere and its transport are addressed in a reduced-form version of a model called Advanced Source Trajectory Regional Air Pollution (ASTRAP). ASTRAP uses 11 years of wind and precipitation data to estimate the variability of model results on the basis of climatological variability. The resulting variability in ambient concentration and deposition estimates is then incorporated into the module to represent climatological variability. This variability is significant when examining the baseline or policy scenarios in a stand-alone manner. However, when the policy scenario concentrations are subtracted from the baseline concentrations to estimate concentration reductions under the policies, much of the year-to-year variability due to climatological differences is canceled out (Bloyd et al., 1996). Hence, we do not include this source of uncertainty in our analysis.

The major previous example of a large emission trading program is the SO_2 trading program initiated under the 1990 Clean Air Act amendments. One of the important surprises that resulted from that program was the dramatic reduction in the cost of emissions (compared to expectations at the time the program was introduced) and many have attributed the decline in cost to the flexibility and incentives associated with the trading program (Carlson et al. 2000). This experience suggests that such a decline in cost may be a characteristic of a comparably sized NO_X trading program, but there is reason to think otherwise. A moderately sized trading program for NO_X has been in place in 11 northeastern states since 1999, providing the same type of incentives to find ways to reduce costs as would the larger program in the SIP Call region, and recent trends in costs of compliance are reflected in our model. One other possibility is that new technologies that accomplish reduction of multiple pollutants at lower cost may emerge if the federal government implements legislation to control multiple pollutants. That policy scenario is outside the scope we study.

To distinguish the effects of market structure from the effects of technical parameters, we decomposed the changes in emissions (Palmer et al., 2001b). The decomposition examined separately the effect of changes in assumptions about transmission growth, availability factors, heat rates, and operating and maintenance costs, as well as assumptions about policies to support renewable energy. Taken separately, none of these assumptions led to changes that were greater than 1.6% of emissions in the baseline. The individual parameters led to both positive and negative changes in emissions when considered independently, and when considered collectively they led to changes of 1.8%. This constitutes just 22% of the change in emissions that result from the change in market structure. Therefore, for this analysis we focus only on uncertainty about the future structure of the market and accept implicitly the conventional wisdom of how technical parameters would change as a consequence.[9]

3. The Models

This study employs the Haiku model to simulate electricity generation and consumption. Changes in emissions that result from policy experiments are fed into an integrated assessment model of atmospheric transport and environmental effects called the Tracking and Analysis Framework (TAF).

The Haiku electricity model simulates equilibrium in regional electricity markets and inter-regional electricity trade with an integrated algorithm for NO_X emission control technology choice.[10] The model calculates electricity demand, electricity prices, the composition of electricity supply, inter-regional electricity trading activity among 13 NERC subregions, and emissions of key pollutants such as NO_X, SO_2 and CO_2 from electricity generation. Three customer classes are represented (residential, industrial, and commercial). Detail about demand functions is provided and supply curves are calculated for four time periods (super-peak, peak, shoulder, and baseload hours) in each of three seasons (summer, winter, and spring/fall). Investment in new generation capacity and retirement of existing facilities are determined endogenously, based on capacity-related costs of providing service in the future ("going forward costs"). Generator dispatch in the model is based on minimization of short run variable costs of generation.

Inter-regional power trading is identified as the level of trading necessary to equilibrate regional electricity prices (accounting for transmission costs and power losses). These inter-regional transactions are constrained by the assumed level of available inter-regional transmission capability as reported by NERC. Factor prices such as the cost of capital and labor are held constant. Fuel price forecasts are calibrated to

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[9] A related source of uncertainty is the assumption about future fuel prices. However, if natural gas supplies become limited, either due to natural availability or regulatory decisionmaking, then we would expect to see more coal-fired generation in both the baseline and in the policy cases we model. The result would be somewhat closer to the scenario involving the effects of marginal cost pricing in the electricity sector.

[10] Haiku was developed by RFF and has been used for a number of reports and articles that appear in the peer-reviewed literature. The model has been compared with other simulation models as part of two series of meetings of Stanford University's Energy Modeling Forum. (Energy Modeling Forum 1998, 2001).

match EIA price forecasts for 2000 (U.S. EIA 1999). The model includes fuel market modules for coal and natural gas that calculate prices that are responsive to factor demand. Coal is differentiated along several dimensions including fuel quality and location of supply, and both coal and natural gas prices are differentiated by point of delivery. All other fuel prices are specified exogenously, with most changing over time.

The algorithm for compliance with NO_X emissions caps in Haiku solves for the least cost set of post-combustion investments. The variable costs of emission controls plus the opportunity cost of emission allowances under cap and trade programs are added to the variable cost of generation in establishing the operation of generation capacity. The post-combustion controls that can be selected in Haiku are selective catalytic reduction (SCR) and selective noncatalytic reduction (SNCR). We have also tried hybrid, which combines SCR and SNCR, and it is never selected as a compliance option, so we removed it as an option to speed up the algorithm. All of the cost and emission control efficiency estimates for both SCR and SNCR are based on a report from Bechtel to EPA on NO_X controls (USEPA, 1998a.)

The changes in emissions of NO_X that result from the policies are fed into the Tracking and Analysis Framework (TAF), a nonproprietary and peer-reviewed integrated assessment model (Bloyd et al., 1996).[11] TAF integrates pollutant transport and deposition (including formation of secondary particulates but excluding ozone), visibility effects, effects on recreational lake fishing through changes in soil and aquatic chemistry, human health effects, and valuation of benefits. We assume that PM 2.5 is about 51% of PM10, and that PM10 is about 55% of total suspended particulates. All effects are evaluated at the state level and changes outside the United States are not evaluated. We report only health-related impacts, which are the lion's share of quantifiable impacts according to previous papers (Krupnick and Burtraw 1996; Burtraw et al. 1998).

[11] TAF was developed in support of the National Acid Precipitation Assessment Program (NAPAP) and is the work of a team of more than 30 modelers and scientists from institutions around the country. Each module of TAF was constructed and refined by a group of experts in that field, and draws primarily on peer reviewed literature to construct the integrated model. As the framework in which these literatures are integrated, TAF itself was subject to an extensive peer review in December 1995, which concluded that "TAF represent[s] a major advancement in our ability to perform integrated assessments" and that the model was ready for use by NAPAP (ORNL, 1995). The entire model is available at www.lumina.com\taflist.

Changes in health status are predicted to result from changes in air pollution concentrations. Impacts are expressed as the number of days acute morbidity effects of various types last, the number of chronic disease cases, and the number of statistical lives lost to premature death, based on C-R functions found in the peer-reviewed literature. The C-R functions are taken, for the most part, from epidemiological articles reviewed in EPA's Criteria Documents that, in turn appear in key EPA cost-benefit analyses, such as the EPA Section 812 prospective and retrospective studies (USEPA, 1997a; USEPA, 1999). The health effects module contains C-R functions for PM10, TSP, SO_2, sulfates (SO_4), NO_2, and nitrates (NO_3). In this paper we examine only changes in concentrations resulting from changes in emissions of NO_X. We ignore changes in concentrations of emissions of SO_2 due to the cap on aggregate emissions.

A variety of mortality concentration-response functions are available in the model using inputs that consist of changes in ambient concentrations of NO_X, and demographic information on the population of interest. For morbidity, changes in NO_2 and NO_3 are modeled according to a scheme designed to avoid double counting of effects—such as symptom days and restricted activity days—using a variety of studies from the literature. NO_X is included for respiratory symptom days, eye irritation days, and phlegm days. The change in the annual number of impacts of each health endpoint is the output that is valued.

The health valuation submodule of TAF assigns monetary values taken from the environmental economics literature to the health effects estimates produced by the health effects module. The benefits are totaled to obtain annual health benefits for each year modeled.

4. Scenarios

We exercise the models to explore the three uncertainties we have identified using scenario analysis. While some studies evaluating uncertainties in the valuation of mortality effects have relied on Monte Carlo simulation using distributions derived from meta-analyses (Desvouges et al. 1998), we find the evaluation of 18 unique scenarios most suitable to our purposes. First, it allows us to display results from a range of prominent and plausible assumptions, while retaining information from the individual studies. Second, the goal of this study is not the arrival at a confidence interval for benefits based on the available literature, but rather the direct comparison of estimates from a number of scenarios on either side of our "preferred" estimates used in earlier research (Burtraw et al. 2001; Palmer et al. 2001a). In particular, we want to observe whether or not the earlier result that an annual policy in the SIP region is preferable to a seasonal policy proves robust over this range of scenarios. Additionally, examining a range of scenarios allows us to gauge under which, if any, assumptions a national annual policy might warrant consideration. In this section we describe two scenarios that are developed to represent the structure of the electricity market, three scenarios to represent epidemiology and three to represent valuation of health effects. Finally, we describe the three policy scenarios that are investigated within this modeling domain.

4.1 Structure of Electricity Market

Because several regions have already restructured their electricity markets, we develop a limited restructuring scenario by assuming that marginal-cost pricing of electricity is implemented in those regions and subregions of the North American Electric Reliability Council (NERC) where most of the population resides in states that have already made a commitment to implement restructuring.[12] All other regions are assumed to price electricity at average cost. The alternative economic regulatory scenario labeled "nationwide restructuring" assumes that restructuring is implemented across the country by 2008. We characterize the limited restructuring scenario as a "low" case because there exist lower emissions in the absence of the NO_X policies. The nationwide scenario is characterized as a "high" case and entails emissions that are about 567,000 tons (10%) greater.

The features that distinguish the scenarios are shown in Table 1. Previous analysis indicates the method of determining price is the most important of these to emissions, electricity price, and demand. In regulated regions the price of generation is based on the average cost of generating electricity, and in competitive regions the price of generation is based on the marginal cost of generating electricity. Another way that prices differ

[12] The states that are assumed to employ competitive pricing in the limited restructuring scenario are California, Texas, and New York, plus the mid-Atlantic and New England states.

between regulated and competitive regions is the pricing of reserve services. In regulated regions, the fixed costs of the units providing reserve services are included in the measure of total cost of service, which is used to calculate average costs of generation. In competitive regions, a linked market to provide reserve services is solved. To maintain incentive compatibility between the generation and reserve markets, the reserve payment is made to all generators providing generation or reserve services.

Table 1 Characterization of economic regulation and distinguishing features in 2008.

Characterization	**Low (Preferred)**	**High**
	Extent of Competition	
	Limited	Nationwide
Pricing Institution	Mix of Regulation and Competition	Competition
Stranded Costs	n/a	Recovery of 90%
Renewables Portfolio Standard	None	Renewable Portfolio Standard
Transmission Capability	No change	10% Expansion
Ratio of Technical Parameter Values 2008 to 1997		
Maximum Availability Factor	1.02	1.04
Heat Rate	0.99	0.97
General and Administrative Cost	0.75	0.67
Nonfuel O&M Cost	0.76	0.70

Also, we assume that the use of time-varying prices of electricity will become more widespread as a result of restructuring. We represent this assumption by assigning time of use prices to industrial customers in any region that has implemented marginal cost pricing. In regulated regions and for residential and commercial customers in all regions, the retail price is assumed to be steady between peak and off-peak times, but can vary across seasons.

The treatment of stranded costs is another characteristic of the nationwide restructuring scenario. Stranded cost refers to the depreciation in the market value of generation assets to a point below book value as a result of the move to a competitive market. We assume that 90% of the difference is recovered as part of a transition fee. The Renewables Portfolio Standard (RPS) refers to the adoption of a policy to require a percentage of the electricity sold to customers be generated using a renewables-based technology. A number of states have already adopted similar policies. We assume there exists a $17 per megawatt-hour (MWh) price cap on tradable renewable credits. Also, transmission capability is assumed to remain constant under limited restructuring but to grow under nationwide restructuring.

The remainder of the variables in the table describe the assumed rates of technical improvement in the fleet of existing generation stations. Productivity change is implemented in the model through changes in four parameters: improvements in the maximum capacity factor at existing generators, reductions in the heat rate at existing coal-fired generators, reductions in operating costs, and reductions in general and administrative costs at all existing generators. Table 1 illustrates the ratio of each variable under each scenario in 2008 and compares it to its value in 1997. All of the assumptions are identical to those set forth for both market structures in Palmer et al. (2001a) and are based on assumptions developed by the collection of energy modelers who participated in Stanford University's Energy Modeling Forum Working Group 17 (Energy Modeling Forum 2001).[13]

4.2 Epidemiology

In accordance with the majority of existing epidemiological literature, we assume a linear concentration response function in all scenarios. We treat nitrates as similar in potency to ordinary PM10. Thus the C-R coefficients used are from studies estimating the statistical relationship between particulate matter concentrations and mortality rates. The range of C-R coefficient assumptions used in this analysis is presented in Table 2.

[13] Burtraw et al. (2001) and Palmer et al. (2001a) employ assumptions that are more optimistic than the Energy Modeling Forum study about how restructuring is likely to improve availability factors and slightly less optimistic about how far general and administrative costs are likely to fall as a result of restructuring.

Table 2. Characterization of epidemiology and concentration-response coefficients.

	Low	**Mid (Preferred)**	**High**
Study	Samet et al. (2000)	Schwartz and Dockery (1992)	Pope et al. (1995)
Mortality Type	Acute	Acute	Chronic
Time Period	1987-1994	1974-1984	1982-1989
Particle Size	PM10	TSP	PM2.5
Population	All ages, 90 U.S. cities	All ages, Steubenville, OH	295,000 participants >30 years of age, 50 U.S cities
C-R coefficient for PM10 (*% Δ mortality per 10 μg/m^3*)	0.46	1.0	3.57

Our low assumption is drawn from Samet et al. (2000), a time-series analysis of PM10 effects on mortality from 1987-1994, which is part of the National Morbidity, Mortality, and Air Pollution Study. The study makes a significant contribution to the literature by using a single analytic approach to analyze the effect of PM10 in a large number of locations, and for its evaluation of differences at the regional level. For the purposes of this analysis, however, we use the 90-city aggregate estimate. This estimate indicates that one can expect to find a 0.46% increase in the mortality rate for an increase of 10 μg/m^3 increase in PM10.

For our central C-R estimate, we employ the mortality relationship from Schwartz and Dockery (1992), another time series study of acute mortality. This is the coefficient that was used in earlier papers examining the relative cost-effectiveness of NO_x policies (Burtraw et al., 2001; Palmer et al., 2001a). Schwartz and Dockery is a time-series analysis of TSP mortality effects in Steubenville, OH, during the years 1974-1984. The estimated C-R relationship for PM10 is a 1.0% increase in the mortality rate per 10 μg/m^3 increase in PM10.

Our high C-R coefficient assumption is drawn from Pope et al. (1995), a study of chronic mortality effects of PM 2.5. A reanalysis of the original study was performed by

Krewski et al. (2000), essentially replicating the original results, and finding them robust to a number of alternative specifications. However, rather than incorporate the coefficient from the reanalysis, we use the original concentration-response relationship from Pope et al. (1995), a 3.57% increase in the mortality rate per 10 $\mu g/m^3$ increase in PM10, as it has been the basis for numerous analyses, most notably the EPA Retrospective and Prospective studies (U.S. EPA 1997a; U.S. EPA 1999). Because the Pope et al. (1995) study population is limited to individuals aged 30 years or older, we limit the application of this C-R coefficient to individuals of the same age range.

4.3 Valuation

To characterize the interesting range of possible values of changes in the risk of premature mortality (VSL) we again use three scenarios. These alternatives are summarized in Table 3.

Table 3 Characterization of mortality valuation.

	Low	**Mid (Preferred)**	**High**
Study	Mrozek and Taylor (2000)	Chestnut et al. (1995)	EPA (1999)
Description	Meta-analysis of 33 wage-risk studies	Age-weighted average based on a combination of wage-risk and CV studies	Estimate derived from combination of 21 wage-risk and 5 CV studies
Mean VSL (millions 1997 dollars)	\$2.17	\$3.84	\$5.90

The low VSL assumption is from Mrozek and Taylor (2002). This study is a meta-analysis of 33 studies of compensating wage differentials that reported a combined total of 203 VSL estimates. For populations facing mortality risks approximately equal to the average risk of accidental death in the workplace, they find a mean VSL of \$2.16 million (1997 dollars).[14] Mrozek and Taylor suggest that wage-risk studies are likely to

[14] This estimate restricts the sample to U.S data sources and Bureau of Labor Statistics risk data, omits high-risk analyses (mean risk greater than 5/10,000), and controls for interindustry wage differentials.

overestimate the value of risk-reduction as a result of falsely attributing wage rate differentials to risk that are actually due to inter-industry differences in wage-rates. This seemingly low estimate is comparable to recent estimates in the valuation literature from studies that attempt to more closely link WTP with the specific nature of injury that results from changes in air pollution (Krupnick et al, 2002 and Alberini et al, 2001).

The central assumption for VSL is Chestnut et al. (1995), which estimates a mean VSL of $3.84 million (1997 dollars). This assumption is used in Burtraw et al. (2001), though in that paper the authors chose not to update the value for inflation as an interpretation of the recent trends in the literature discussed above. Here, however, we have adjusted the VSL to account for inflation. Chestnut and coauthors choose a low, central, and high VSL and assign probability weights to each, based largely on the extent to which the existing literature supports the value in order to achieve their benefits estimate.

The high estimate is from EPA (1999). This analysis pooled 26 value of life studies (five contingent valuation, 21 wage-risk) to derive a Weibull distribution with a mean of $5.9 million (1997 dollars) and a standard deviation of $3.99 million. The EPA uses this VSL in its Section 812 Retrospective and Prospective studies (U.S. EPA, 1997a; U.S. EPA, 1999), and it falls well within the acceptable range of VSL estimates. However, three criticisms of earlier VSL studies, particularly wage-risk studies, can be extended to EPA’s estimate and support its characterization as a high assumption. First, EPA’s chosen value is drawn primarily from studies of prime-age working males who face small risks of workplace mortality. Second, given the suggestion of Mrozek and Taylor (2002) that VSL estimates from wage-risk studies exceeding $2 million to 3 million ($1998) are likely to suffer from inadequate control of inter-industry wage differentials, and EPA’s derivation of a VSL from numerous studies falling into this category, it seems plausible that EPA’s chosen value is biased upward. Finally, it does not reflect recent innovations in study designs, discussed above, that seem to be producing a downward trend in VSL estimates.

4.4 Policies

The uncertain variables are collected in 18 combinations (2x3x3), and each is examined under a baseline and three NO_X policies. The baseline *NO_X* policy scenario includes the NO_X trading program (known as "Phase II") in the northeastern ozone transport region (OTR) but excludes new policies to reduce NO_X in the multi-state SIP Call region. There is a separate baseline for each market structure (limited restructuring and nationwide restructuring). All changes in emissions, benefits, and costs stemming from NO_X policies are measured relative to the respective baseline for a given market structure.[15]

The NO_X policy scenario labeled SIP Seasonal corresponds to EPA's proposed program described previously as the NO_X SIP Call. This scenario includes a five-month summer ozone program implemented in the eastern United States that is represented by the regions in our model that are approximately equal to the SIP Call region.[16] The emissions cap under this policy is 444,300 tons per five-month summer season within the SIP Call region in year 2008. This compares with an emission level of 1.465 million tons in the baseline NO_X scenario under limited restructuring and 1.625 million tons in the baseline NO_X scenario under nationwide restructuring. This emission cap was determined by applying the emissions rate of 0.15 lb per MMBtu to fossil-fired generation in 1997, and hence the emission cap under the policy does not vary according to assumption about market structure. [17]

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[15] In the baseline we assume 82% of coal-fired units have low NO_X burners, including wall-fired units (70% of coal-fired capacity) and tangentially-fired units (12%). In addition, we assume tangentially-fired units have over-fire air.

[16] These regions include NE (New England); MAAC (Maryland, District of Columbia, Delaware, and New Jersey; most of Pennsylvania); New York; STV (Tennessee, Alabama, Georgia, South Carolina, and North Carolina; parts of Virginia, Mississippi, Kentucky, and Florida); ECAR (Michigan, Indiana, Ohio, and West Virginia; parts of Kentucky, Virginia, and Pennsylvania); and MAIN (most of Illinois and Wisconsin; part of Missouri). These regions exclude a small portion of western Missouri that is part of the 19 states covered by the SIP Call, and small parts of Illinois and Wisconsin. These regions include the eastern half of Mississippi, Vermont, New Hampshire, and Maine, which are not part of the SIP Call region. However, the other New England states—Connecticut, Massachusetts, and Rhode Island—are part of the eastern region covered by the OTR. The reconciliation of these two programs may ultimately involve their participation.

[17] This is the same methodology applied by EPA. Forecast electricity generation varies slightly in our model, and the geographic coverage varies slightly, from the EPA model (U.S. EPA 1998a, 1998b, 1999).

The second NO_X policy scenario is SIP Annual. Here, the average emissions rate achieved during the five-month summer season for the SIP Call region is extended to an annual basis. The annual emissions cap under this policy is 1.06 million tons per year within the SIP region in year 2008. This compares with an emission level of 3.449 million tons in the baseline NO_X scenario under limited restructuring and 3.866 in the baseline NO_X scenario under nationwide restructuring.

The third NO_X policy scenario is National Annual. In this scenario the average emission rate for the SIP Call region is applied to the entire nation on an annual basis. The annual emissions cap for the nation under this policy is 1.6 million tons per year. This compares with an emission level of 5.533 million tons in the baseline NO_X scenario under limited restructuring and 6.1 million tons in the baseline NO_X scenario under nationwide restructuring.

In both of the alternative NO_X policy scenarios, we assume the policy is announced in 2001 and implemented in 2004. We report results for 2008, hoping thereby to avoid transitional difficulties in implementing the policy that may characterize the first years of the program (NERC 2000).

5. Results

Our motivation is to investigate the relative cost-effectiveness of options, given that a policy to address ozone will be implemented. Hence, the results are oriented to present the cost-effectiveness of the options relative to the currently planned SIP Seasonal policy. In presenting these results, we are also able to comment on the role of benefits and costs that we do not consider in the cost-effectiveness analyses, and to the desirability of the current policy proposal compared to no policy at all. Also, we achieve insights into the value of additional information about omitted benefits.

5.1 Emissions

Since the SIP seasonal program is aimed at reducing the summer-time ground-level ozone concentration, one of the primary concerns while extending the program to an annual one is the increase in the SIP regional summer NO_X emissions. Table 4 indicates that the regional summer NO_X emissions in the SIP region in 2008 are below the seasonal cap off 444,300 tons under both the SIP annual and the national annual policies.[18] Furthermore, the national annual policy does not lead to an increase in emissions in the SIP region compared to the SIP annual policy. These results are valid under both restructuring scenarios.

Table 4 NO_X emissions: national and SIP regional; summer and annual in 2008.

	Summer NO_X Emissions (thousand tons)			**Annual NO_X Emissions** (thousand tons)		
	SIP	Non-SIP	National	SIP	Non-SIP	National
Limited Restructuring						
Baseline	1,445	932	2,377	3,449	2,084	5,533
SIP Seasonal	421	955	1,376	2,418	2,123	4,541
SIP Annual	441	941	1,382	1,041	2,114	3,155
National Annual	395	285	679	921	650	1,571
Nationwide Restructuring						
Baseline	1,625	985	2,610	3,866	2,234	6,100
SIP Seasonal	437	1,001	1,438	2,672	2,238	4,910
SIP Annual	444	976	1,420	1,048	2,219	3,267
National Annual	400	288	688	942	652	1,594

In general, the NO_X emissions are higher under nationwide restructuring as compared with limited restructuring for all three NO_X policies, except where they are capped under the national annual policy. This is primarily due to the increased utilization of existing coal plants that occurs due to the faster improvements in the efficiency and the costs associated with them, as indicated in Table 1.

[18] Variations under the cap are due to projected over-complinace in 2008 and to approximation in convergence in the simulation model.

5.2 Costs

NO_X emissions from power plants can be reduced by: (1) installation of post-combustion controls; (2) input substitution—for example, substituting gas generation for coal generation; or (3) reduction in total generation. We find the installation of post-combustion controls accounts for the vast majority of emission reductions under all scenarios and policies, but the choice of which type of control and the contribution of other ways to reduce emissions varies.[19]

Under all of the policies, well over 95% of coal-fired power plants are retrofitted with post combustion controls. Under the policies targeting just the SIP region, about 210 gigawatts (GW) of generation is retrofitted with post-combustion controls under each market structure scenario.

The second column of Table 5 reports that the SIP Seasonal policy induces 68% of the controls to be SCR under limited restructuring, and 80% to be SCR under nationwide restructuring. The remaining portion is controlled with SNCR. When the SIP Seasonal policy is extended to the SIP Annual or the National Annual level the percent of capacity that is controlled with SCR grows substantially. This happens because SCR is relatively more capital intensive than SNCR. Under an annual policy, the controls will operate over more kWh per year, which means the average cost of emission reductions is less than under a seasonal policy. The percent of compliance costs that are capital costs are reported in Table 5. The greatest percent occurs under the SIP Seasonal policy, because the controls operate over the fewest kWh under a seasonal policy.

[19] Palmer et al. (2001) report that a welfare measure of cost, in terms of changes in consumer and producer surplus within the electricity sector, yields somewhat lower values than the resource cost of post-combustion control because, typically, electricity is not priced efficiently, and often marginal cost is greater than electricity price. We find the change in surplus is somewhat less than the resource cost in the cases they study, ranging from 82% of compliance cost in the case of the SIP Seasonal policy under limited restructuring to 98% of compliance cost in the case of the SIP Annual policy under nationwide restructuring. However, under the National Annual policy, the difference is more substantial. In the case of limited restructuring, the welfare cost is just 39% of compliance cost, because outside the SIP Call region most of the nation has regulated prices. In the case of nationwide restructuring the situation is reversed and the change in economic surplus is 127% of compliance cost. We do not include welfare effects in this analysis because it is a significant departure from the measure of resource costs that forms the basis for most of the policy and economic debate (U.S. EIA, 2001). However, future research should consider such effects.

Under the National Annual policy we find that virtually all of the coal-fired plants that can install post-combustion controls have installed them, with the majority selecting SCR. However, this is not sufficient to achieve the required emission reductions. The need for further emission reductions leads to increasingly expensive installations at a small number of oil-fired or gas-fired facilities, which pushes up the marginal cost of compliance and creates a larger role for other ways to reduce emissions.

Table 5. Capacity that installs post-combustion controls, type of controls, and total and marginal control costs in 2008 by market structure.

	Controlled Capacity (GW)	**Percent SCR**	**Percent of Total Control Costs**			**Total Control Costs** (million 1997$)
			Variable O&M	Fixed O&M	Capital	
Limited Restructuring						
Baseline	11.4	0.0	47.6	6.0	46.4	30
SIP Seasonal	213.0	67.7	8.0	38.5	53.6	2,176
SIP Annual	211.4	80.2	15.7	35.9	48.4	2,758
National Annual	333.5	92.3	12.8	37.5	49.8	4,464
Nationwide Restructuring						
Baseline	12.4	0.0	47.6	6.0	46.4	33
SIP Seasonal	208.7	80.5	7.5	39.5	53.0	2,486
SIP Annual	204.6	90.7	14.8	36.8	48.4	2,899
National Annual	332.3	94.9	13.2	37.3	49.5	4,531

Substitution of gas for coal plays a somewhat more important role in reducing emissions under the National Annual policy with nationwide restructuring. In this case, coal-fired generation is 6.4% less than in the baseline and gas-fired generation is 9.6% greater. In other cases we see small variation in the amount of coal and gas generation.

The third way to achieve emission reductions is to reduce electricity consumption and total generation. Under both restructuring scenarios, the policies targeting the SIP region yield almost no change in total generation from baseline quantities. Only the National Annual policy produces noticeable reductions in total generation. Under the limited restructuring scenario the reduction is 2%; under the nationwide restructuring scenario the reduction is 1%.

The small change in total generation is related to the small effect that the NO_X policies have on electricity price. National electricity price falls slightly under the SIP Seasonal policy compared to baseline with limited restructuring, as indicated in the right column of Table 6. The price falls due to the small changes in gas-fired generation in some regions, which determines marginal generation cost and price in competitive regions, and small changes in electricity transmission. As a consequence, the bulk of the resource cost of post-combustion controls are borne by producers in this case. Under the nationwide restructuring scenario there is substantially greater use of coal for electricity generation in the baseline. Consequently, the introduction of the SIP Seasonal policy under nationwide restructuring imposes relatively greater opportunity cost by requiring a greater quantity of emission reductions through abatement or through reducing coal-fired generation, and this is reflected in the change in electricity price.

Under both restructuring scenarios the increase in electricity price due to the SIP Annual policy is almost zero, even though the total cost of pollution control goes up by around \$500 million (1997 dollars) compared to the SIP Seasonal policy. The reason is that it is more cost-effective to install SCR than SNCR when the amount of emissions reductions required are greater, as noted previously. Marginal compliance costs fall, compared to the SIP Seasonal policy, resulting in lower NO_X permit prices that offset the increased cost of post-combustion control.

The increase in price under the National Annual policy is small under the limited restructuring scenario. This follows from the regulation of electricity price in much of the nation that is brought into compliance under the national emission cap. Under regulation, price adjusts sufficiently to cover the change in total cost. However, under nationwide restructuring, the National Annual policy is determined by marginal generation cost and the effect is more variable, depending on the characteristics of generation capacity and costs.

Table 6. Characteristics of electricity generation in 2008 by market structure.

	Generation (million MWh)			**Electricity Price** (1997$/MWh)
	Coal	Gas	Total	
Limited Restructuring				
Baseline	1,767	1,182	3,996	62.2
SIP Seasonal	1,759	1,221	3,997	62.0
SIP Annual	1,784	1,203	4,010	62.1
National Annual	1,755	1,135	3,917	62.5
Nationwide Restructuring				
Baseline	1,997	941	4,032	60.1
SIP Seasonal	1,972	961	4,020	60.7
SIP Annual	1,971	962	4,019	60.9
National Annual	1,870	1,031	3,991	62.1

5.3 Benefits

Benefits from particulate-related changes in human morbidity and mortality are calculated under each scenario. For convenience we repeat that our preferred set of assumptions are limited restructuring, Schwartz and Dockery (1992) C-R coefficient, and Chestnut et al. (1995) VSL. Under preferred assumptions, morbidity effects account for between $199 million and $698 million (1997 dollars) over the three policy scenarios, or about 21% of total health benefits. Mortality effects account for $726 million to $2,452 million (1997 dollars) over the three policies, which is the remaining portion of benefits we estimate. The relatively small contribution from morbidity to total health benefits is consistent with the current literature and our decision to focus on uncertainty specific to mortality benefits. Because we do not examine uncertainties in morbidity effects, morbidity benefits change only with changes in emissions implicit in the different policy scenarios. Over the entire range of scenarios, therefore, morbidity benefits vary by a relatively narrow range, from \$199 million to \$763 million (1997 dollars).

In contrast, mortality benefits vary substantially over the chosen range of epidemiology and valuation uncertainties. Mortality benefits range from \$191 million to \$9,115 million (1997 dollars) among the scenarios. This constitutes a range of 49% (under the scenario yielding the lowest benefits, mortality benefits are actually slightly lower than morbidity benefits) to 92% of total benefits, which range from \$390 million to \$9,878 million (1997 dollars).

5.4 Net Benefits and Cost-Effectiveness

The basis for the evaluation of the cost-effectiveness of the policies is benefits minus costs, or net benefits. Although in many cases we find negative net benefits, one can infer little from this because potentially important benefits and costs are excluded from the analysis. In these cases, one would have to consider omitted benefits in order to argue that total benefits may exceed total costs. Nonetheless, the estimate of partial net benefits based solely on particulate-related health benefits provides robust conclusions about the relative cost-effectiveness of the policies in many of the scenarios examined. By comparing the value of partial net benefits of the different policies, we can show that net benefits would increase, often substantially, through the choice of a more cost-effective policy. The value of net benefits for each policy under each scenario is reported in Table 7. We discuss net benefits from both a national and regional perspective.

5.4.1 The National Perspective

The main finding is that under each of the 18 uncertainty scenarios we consider, the net benefits under a SIP Annual policy are at least as great as those expected under the EPA's currently planned policy to implement a seasonal cap. The preferred (midpoint) assumptions lead to additional net benefits of \$724 million per year under an annual policy compared to a seasonal one, but among all the scenarios additional net benefits of an annual policy range from \$0 up to \$3 billion per year (1997 dollars).

Table 7: Net benefits in 2008 (million 1997 dollars). Preferred scenario is shaded.

Epidemiology:	**Low**			**Mid**			**High**		
Valuation:	**Low**	**Mid**	**High**	**Low**	**Mid**	**High**	**Low**	**Mid**	**High**
Baseline Emissions: **Low** (Limited Restructuring)									
SIP Seasonal	-1,756	-1,612	-1,460	-1,534	-1,220	-846	-1,060	-383	440
SIP Annual	-1,793	-1,454	-1,090	-1,268	-496	407	-136	1,554	3,484
National Annual	-3,092	-2,612	-2,083	-2,334	-1,294	64	-729	1,562	4,508
Baseline Emissions: **High** (Nationwide Restructuring)									
SIP Seasonal	-2,004	-1,841	-1,654	-1,750	-1,383	-958	-1,197	-415	550
SIP Annual	-1,806	-1,415	-1,008	-1,203	-354	692	92	1,932	4,291
National Annual	-3,007	-2,463	-1,881	-2,179	-978	478	-370	2,177	5,377

Key: Market Structure and Baseline Emissions: Low (Limited Restructuring), High (Nationwide Restructuring)
Epidemiology (C-R): Low (Samet et al. 2000), Mid (Schwartz and Dockery 1992), High (Pope et al. 1995)
Valuation (VSL): Low (Mrozek and Taylor, 2000), Mid (Chestnut et al. 1995), High (EPA, 1999).

The greatest variation in net benefits results from the range of epidemiological assumptions that we investigate, though the variation attributable to the range of valuation scenarios also is large. In contrast, the choice of market structure plays a relatively small role in the variation in the calculation of net benefits. Under nationwide restructuring, all of the policies tend to yield systematically higher net benefits than under limited restructuring. The relative cost-effectiveness of the policies is not very sensitive to this the restructuring scenario, although it may be important to a benefit-cost analysis.

A graphic comparison of the net benefits for the nation of the three policies under all the scenarios is presented in Figure 2. The net benefits for the SIP Seasonal policy are presented as monotonically increasing in the figure. For every scenario, the comparable net benefits of the SIP Annual policy lie above those for the SIP Seasonal. The National Annual benefits are above those of the SIP Seasonal in half of the scenarios.

We reason that consideration of omitted benefits, such as reduced nitrogen deposition and ozone, would strengthen the finding that an annual policy in the SIP Call region is more cost-effective than a seasonal policy. Benefits from omitted effects would always accrue to the national policy in at least as great a measure as they would accrue to the seasonal policy. The benefits of reduced nitrogen deposition would accrue substantially in the winter months under the annual policy. Hence, the inclusion of omitted benefits would not change the results. We find there is sufficient information to conclude that an annual policy is preferable to a seasonal policy in the SIP Call region.

In contrast, a second main finding is that a greater understanding of the benefit pathways that are excluded from the analysis is important to obtaining an ordinal ranking of the cost-effectiveness of the National Annual policy compared to the other policies. Under preferred values for uncertain parameters, the current SIP Seasonal policy is preferable by a small amount compared to a National Annual policy. But, Figure 2 illustrates that, in half of the scenarios we examine, the National Annual policy is more cost-effective. We reason the relative performance of the National Annual policy compared to the SIP Seasonal policy could only be strengthened by consideration of omitted benefits. Similarly, a comparison of the National Annual policy with the SIP Annual policy is not robust to the inclusion of omitted benefits because benefits that accrue outside the SIP region would augment only the net benefits of the National Annual policy.

Figure 2: Net benefits for the nation, 2008.

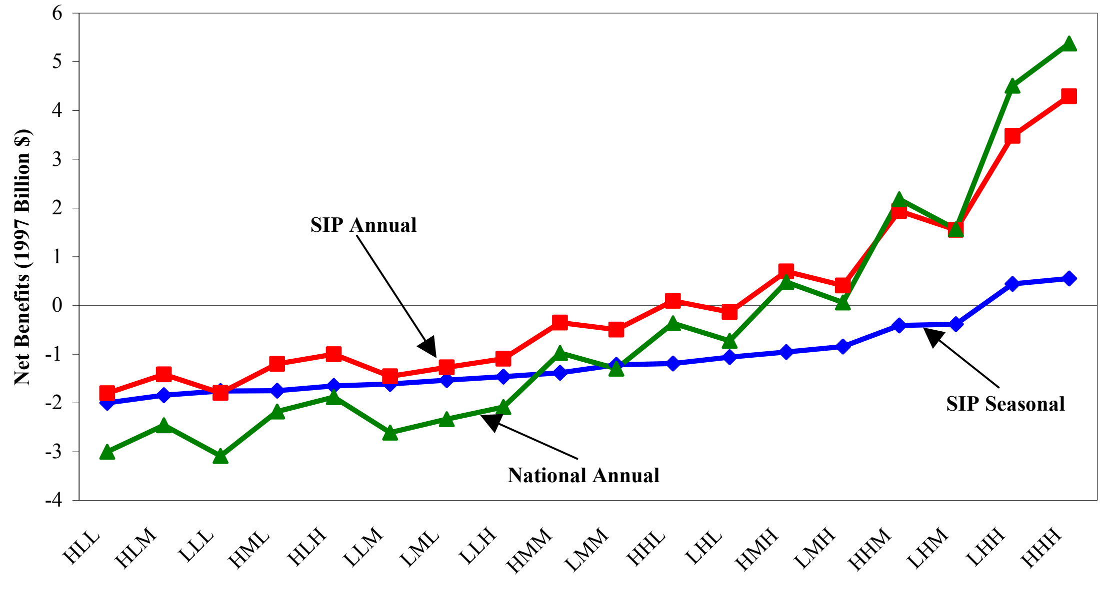
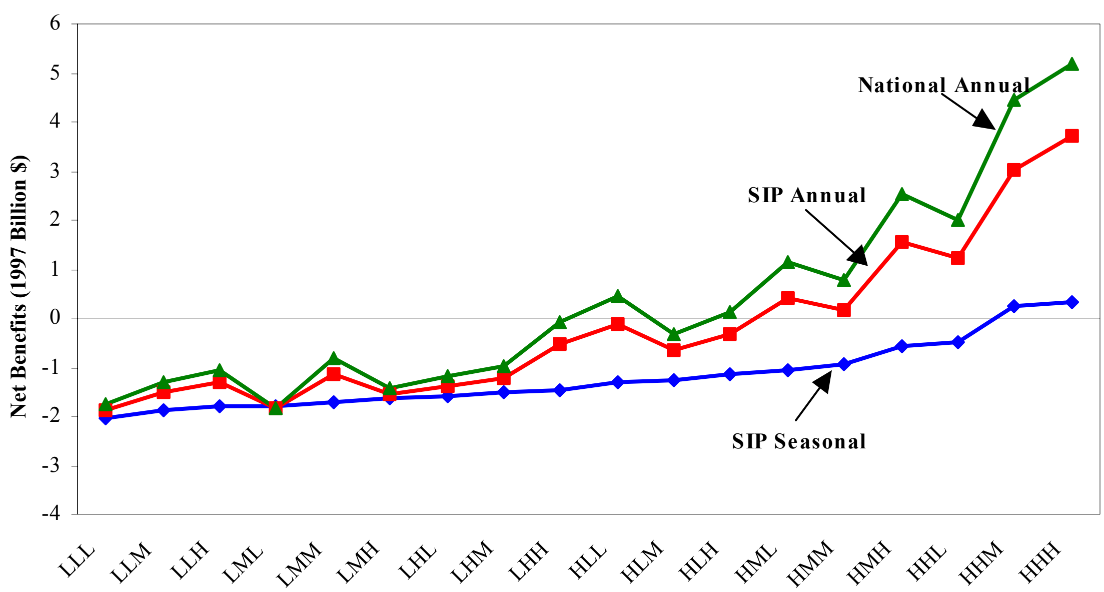


Figure 3: Net benefits in the SIP Region, 2008.



5.4.2 The Regional Perspective

A regional perspective on the expected net benefits is relevant, given the regulatory setting for the policies we consider. Even if the EPA was supportive of an annual policy, it could not impose one as part of the SIP Call because it is justified on the basis of controlling ozone, which is a seasonal problem. The EPA lacks authority to mandate annual reductions in NO_X until particulate-related legislation, such as the PM2.5 standard or the regional haze standard, becomes a reality, which in any event would be years in the future. It is incumbent on state pollution officers to decide how to implement the SIP Call emission reduction requirements, and they could choose to adopt an annual program.

Therefore, we are interested in investigating the incentives at the regional level to implement emission reductions. Figure 3 illustrates the net benefits that are achieved in the SIP region under the policies, excluding benefits that accrue to the rest of the nation. Since all of the costs of policies in the SIP region accrue within the region, but a fraction of the benefits spill over to states outside the region, net benefits within the SIP region under policies exclusive to the region are less than net benefits to the nation as a whole. This result holds for either SIP-exclusive policy, though a greater amount of benefits spill over under the SIP Annual policy than under the SIP Seasonal policy. From the perspective of the SIP region, the SIP Annual policy is more cost-effective than the SIP Seasonal policy under all scenarios. Over the 18 scenarios examined, net benefits are between \$77 million and \$2,761 million greater under the SIP Annual policy compared to the SIP Seasonal policy.

However, there is a substantial difference when evaluating the net benefits of the National Annual policy from a regional perspective. An important part of the costs under the National Annual policy accrue outside the SIP region, and some of the benefits from emission reductions outside the region spill over into the SIP region. Therefore, the picture of net benefits in the SIP region under the National Annual policy is substantially improved. Figure 3 illustrates that, from the perspective of the SIP region, a National Annual policy such as might be embodied in proposed legislation would be more cost-effective than either an annual or a seasonal policy in the SIP region. This result is robust across all of the uncertainty scenarios.

There is another important distinction to be made between the 11 northeastern states known as the OTR that have been participating in a summertime NO_X trading program since 1999, and the remainder of the states in the SIP region that have been less receptive to the requirements of the SIP Call. The remaining states outside the OTR represent the lion's share of emissions in the region and therefore they will bear the lion's share of the costs of emission reductions. In addition, since emissions are thought to drift prevalently from the west toward the northeast, it is likely that the northeastern states capture most of the benefits. Therefore, it is interesting to observe whether the net benefits accrue largely to the 11 northeastern states to the exclusion of the other eight states. In order to gain insight into this question, one can compare Figure 4, which includes just the eight states outside the OTR, with Figure 3, which includes the entire SIP region.

Figure 4 illustrates there is less incentive for the states outside the northeast to embrace the SIP Annual policy in place of the SIP Seasonal policy than there is in the northeastern states. For the SIP seasonal policy in non-OTR states, net benefits range from -\$2,126 to -\$541 million over the 18 scenarios. For the SIP Annual policy, the range is from -\$2,118 to \$1,531 million. In roughly half of the scenarios there is little difference between the policies from the perspective of these states, but in the other half of the scenarios there are significantly greater net benefits under the SIP Annual policy in the non-OTR states. Our preferred assumptions fall into the latter category, with net benefits under the SIP Annual policy about \$300 million greater compared to the SIP Seasonal policy. In no scenario are net benefits substantially less under the SIP Annual policy. Therefore, although enthusiasm for embracing an annual policy in the SIP region may be somewhat muted in the states outside the northeast, there is no scenario under which it is a losing proposition for these states in comparison to the SIP Seasonal policy. Again, we note that consideration of omitted benefits—such as reduced nitrogen deposition and ozone in the sub-region—would strengthen the measure of the annual policy in the SIP Call region relative to a seasonal policy.

Figure 4: Net benefits in the eight states in the SIP region that are not part of the northeastern Ozone Transport Region, 2008.

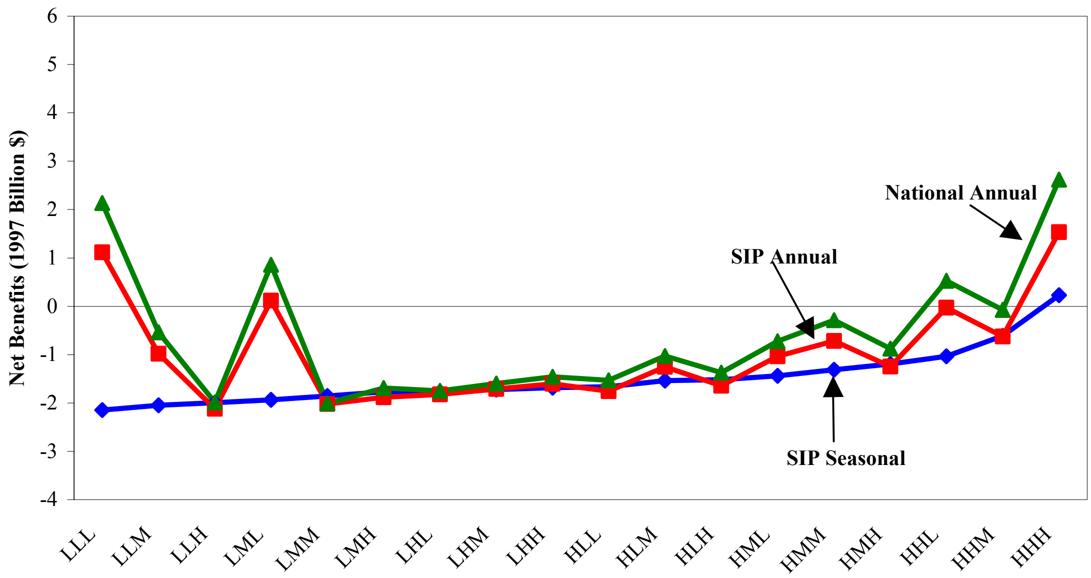
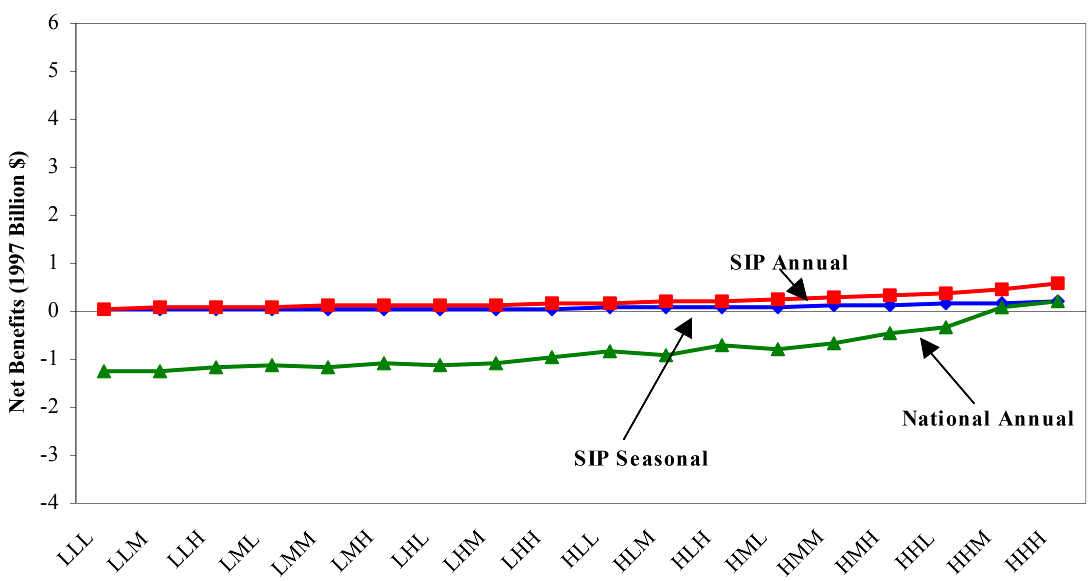


Figure 5: Net benefits outside the SIP region, 2008.



Modest net benefits accrue to states outside the SIP region under the SIP Annual and the SIP Seasonal policies, as illustrated in Figure 5. Under SIP Seasonal, net benefits in non-SIP states range from $23 million to $228 million and, under SIP Annual, net benefits to these states are between $62 million and $570 million. However, the National Annual policy generally leads to fewer net benefits because of the significant costs the policy imposes on this portion of the country, as well as the low population density in this region relative to the SIP region, which implies fewer health benefits. In all but two scenarios, the area outside the SIP region does not achieve net benefits under the National Annual policy that approximate those that are achieved under the SIP Seasonal policy. Again, we find that a better understanding of benefits omitted from the analysis would be important to justifying the desirability of the National Annual policy from a western perspective.

5.5 Omitted Benefits

This analysis provides only a partial accounting of benefits and costs, which is not sufficient to address the wisdom of the currently proposed policy. Nonetheless, based on this partial accounting, one can infer the magnitude of the omitted benefits that would be necessary for any of the policies to yield benefits in excess of costs.

Under our preferred scenario, omitted benefits would need to be worth about $1.2 billion per year for net benefits to be positive under the SIP Seasonal policy. This translates into $1,200 per ton of NO_X reduced during the summer ozone season. Under the SIP Annual policy, omitted benefits would need to be worth about $500 million to achieve positive net benefits. If all of the omitted benefits were related to ozone and were to accrue just during the five-month summer ozone season (thereby ignoring the effects of nitrogen deposition which occurs over the entire year) then the omitted benefits under the SIP Annual policy would need to be worth about $500 per ton to achieve positive net benefits. Under a National Annual policy, omitted benefits would need to total about $1.3 billion, or about $800 per ton if they were to accrue just during the summer ozone season.

Table 8: Benefits and costs of NO_X reductions in the literature.

(1997 dollars per ton NO_X)	Benefits		Costs	Comments
	PM	**Ozone**		
Policies:				
SIP Seasonal	379-2,606		2,064-2,163	Sources in SIP Region and health benefits throughout US
SIP Annual	375-2,612		1,013-1,147	Sources in SIP Region and health benefits throughout US
National Annual	332-2,257		999-1,119	Sources and health benefits throughout US
Previous Studies:				
Burtraw et al. (1998)	739			Sources and benefits throughout US
Banzhaf et al. (1996)	35-366	29-358		Benefits in parts of Minnesota, Wisconsin only
Rowe et al. (1996)	1,071-1,140			Sources in NY State; benefits throughout US and combine PM and ozone
Krupnick et al. (2000)		167	1,032	Sources and benefits in subset of SIP Region; average cost includes reductions over twelve months
USEPA (1998b)			1,807	Sources in SIP region; lower Baseline emissions
USEPA (1998c)	714-2,504	34-1,689		Only health
	297	325-717		Only nitrogen deposition for PM, only agriculture and forestry for ozone
	1,011-2,801	359-2,406		**Sum** of health and other benefits

Table 8 reports the range of net benefits that we identify for the policies, measured in dollars per ton of NO_X emissions reduced, and it provides a glimpse of the possible magnitude of the omitted benefits based on a comparison of our results with previous studies. The most comprehensive of these (U.S. EPA, 1998c) finds a range for ozone-related benefits that is somewhat less but roughly comparable to the range for particulate-related benefits, reaching from $359 to $2,406 per ton. The higher number would result if a link between ozone and premature mortality were established, analogous to the well-established link with respect to particulates. If ozone benefits fall toward the middle of this range, then the SIP Seasonal policy would achieve net benefits that were approximately positive. However, the SIP Annual policy would yield sizable positive net benefits under this circumstance, and it would likely yield positive net benefits even if ozone benefits fell toward the lower end of its range. A National Annual policy also could yield substantial net benefits compared to the SIP Seasonal policy.

We note again that the omitted benefits would not alter the relative cost-effectiveness of the SIP Annual policy compared to the SIP Seasonal policy. Without the inclusion of these benefits, the SIP Annual policy appears more cost-effective under every scenario. Inclusion of these benefits only strengthens this result. Additional summertime benefits would be realized under both policies, and additional wintertime benefits would be realized only under the annual policy. Hence, the standing of the SIP Annual policy can only be strengthened through the inclusion of omitted benefits.

However, the cost-effectiveness of the National Annual policy relative to the other policies could be affected by consideration of omitted benefits, because its relative standing varies across the scenarios we examine. Benefits that accrue in the wintertime would boost the cost-effectiveness of the policy relative to the SIP Seasonal policy. Also, the inclusion of ozone-related benefits may boost the policy relative to the SIP Annual policy, because in many western states ozone benefits may accrue during winter months. And of course, the magnitude of omitted benefits may vary significantly with the geography and demography of different regions.

6. Conclusion

The next large policy to reduce air pollution in the United States is likely to be the implementation of a regional and seasonal cap and trade program for NO_X known as the NO_X SIP Call trading program, which is expected to take form in 2004. This paper identifies three major categories of uncertainty about the benefits and costs of such a policy. One source of uncertainty is the future structure of the electricity market. A second is the epidemiological relationship between nitrates and premature mortality, and a third is the economic valuation of premature mortality. We evaluated 18 scenarios intended to span the set of plausible and commonly accepted visions of those uncertain elements.

The paper examines three policy options. One is the currently planned policy for the eastern states known as the SIP region, labeled SIP Seasonal. Another, labeled SIP Annual, would extend the current policy to an annual basis in the SIP region. The third would extend the policy to be National Annual. A partial assessment of net benefits is used to compare the cost-effectiveness of the policies in the face of the uncertainties that are identified.

The primary finding is that the SIP Annual policy appears more cost-effective than the SIP Seasonal policy in all 18 scenarios that are examined. The consideration of omitted benefits would only strengthen this ordinal ranking of the policies. The subset of the SIP region that includes 11 northeastern states in the OTR would benefit the most under the SIP Annual policy relative to SIP Seasonal, and the remaining eight states in the SIP region would benefit the least, but under no scenario are the remaining eight states made worse off due to the shift to the SIP Annual policy.

One cannot make a similar claim about the relative cost-effectiveness of the National Annual policy. In half of the scenarios we examine, the National Annual policy appears more cost-effective than a SIP Seasonal policy, and in about half the order is reversed. However, the cost-effectiveness of a National Annual policy relative to the other policies is sensitive to benefits omitted from this analysis.

This analysis has not explored the wisdom of the currently proposed policy compared to no policy, primarily because we assume that implementation of a policy at least as rigorous as the SIP Seasonal policy is required legally in order to meet federal clean air goals. Also, we provide only a partial accounting of benefits and costs, which is not sufficient to address the wisdom of the current policy.

Nonetheless, based on this partial accounting, one can infer the magnitude of the omitted benefits that would be necessary for any of the policies to yield benefits in excess of costs. If ozone benefits fall toward the middle of the range identified in previous studies, then the SIP Seasonal policy would achieve small positive net benefits. However, the SIP Annual policy would yield sizeable positive net benefits under this circumstance, and it would yield positive net benefits even if ozone benefits fall toward the lower end of its range. A National Annual policy also would yield positive net benefits in most scenarios if ozone benefits fall toward the middle or even toward the lower end of the range.

In conclusion, we find that a SIP Annual policy is more cost-effective than a SIP Seasonal policy from a national and a regional perspective in every scenario we examine. A National Annual policy is likely to be more cost effective than a SIP Seasonal policy, but this depends on the value of omitted benefits and the scenario that is examined. Our findings support the conclusion of previous studies that the EPA and the states affected by the SIP Call should consider an annual alternative to the current seasonal approach to controlling NO_X emissions.

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