August 16, 2010 External Review Draft

The Benefits and Costs of the Clean Air Act: 1990 to 2020 – Summary Report

US Environmental Protection Agency

Office of Air and Radiation

8/16/2010

Acknowledgements

This document is an abridged version of a longer report which evaluates the benefits and costs of programs implemented pursuant to the 1990 Clean Air Act Amendments. The longer report in turn summarizes and integrates a series of technical analyses examining particular analytical tasks, such as estimation of compliance cost and projection of air quality changes. For references to underlying data, readers are encouraged to consult the full integrated report and the supporting technical analysis documents. These documents are available at: *www.epa.gov/oar/sect812*.

The study was led by staff from the US Environmental Protection Agency Office of Air and Radiation, with support provided, under contract to EPA, by the organizations participating on the Study Team.

The full integrated report has been reviewed by the EPA Science Advisory Board's Advisory Council on Clean Air Compliance Analysis (hereafter Council) and its three technical subcommittees. Particular detailed reports focused on each of the key analytical components of the overall study were also reviewed by the Council and/or one or more relevant subcommittees.

Study Team

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Study Review

Advisory Council on Clean Air Compliance Analysis
Air Quality Modeling Subcommittee
Health Effects Subcommittee
Ecological Effects Subcommittee

The study was greatly improved by the ideas and expertise of the individuals and firms participating on the Study Team, and by the rigorous and thoughtful expert review by the external review panels. However, responsibility for the study's results, the analytical decisions leading to those results, the interpretations reported herein, and the recommendations made for future efforts rests with the Environmental Protection Agency.

Summary of Findings

- The effects of the 1990 Clean Air Act estimated herein reflect actions and partnerships across multiple levels of government, private organizations, households, and individuals. This combined effort involves federal standard setting and implementation, State and local programs to meet federal standards, and expenditures by private entities to achieve the requisite emissions reductions.

- These combined public and private efforts to meet the requirements of the 1990 Clean Air Act Amendments –based on the particular scenarios of Clean Air Act compliance analyzed—rise throughout the 1990 to 2020 period of the study, and are expected to reach about $65 billion annually by 2020.

- Though costly, these efforts are projected to yield substantial air quality improvements which lead to significant reductions in air pollution-related premature death and illness, improved economic welfare of Americans, and better environmental conditions. The economic value of these improvements is estimated to reach almost $2 trillion for the year 2020, a value which vastly exceeds the costs of efforts to comply with the 1990 Clean Air Act and related programs.

- The finding that the benefits of the 1990 Clean Air Act and related programs exceed costs appears robust despite uncertainties in the estimates for both benefits and costs presented in this study. In addition to omitting a wide range of potentially important beneficial effects, analysis of uncertainties in the benefits and costs which could be quantified indicates that the chances are extremely small that direct costs exceed direct benefits.

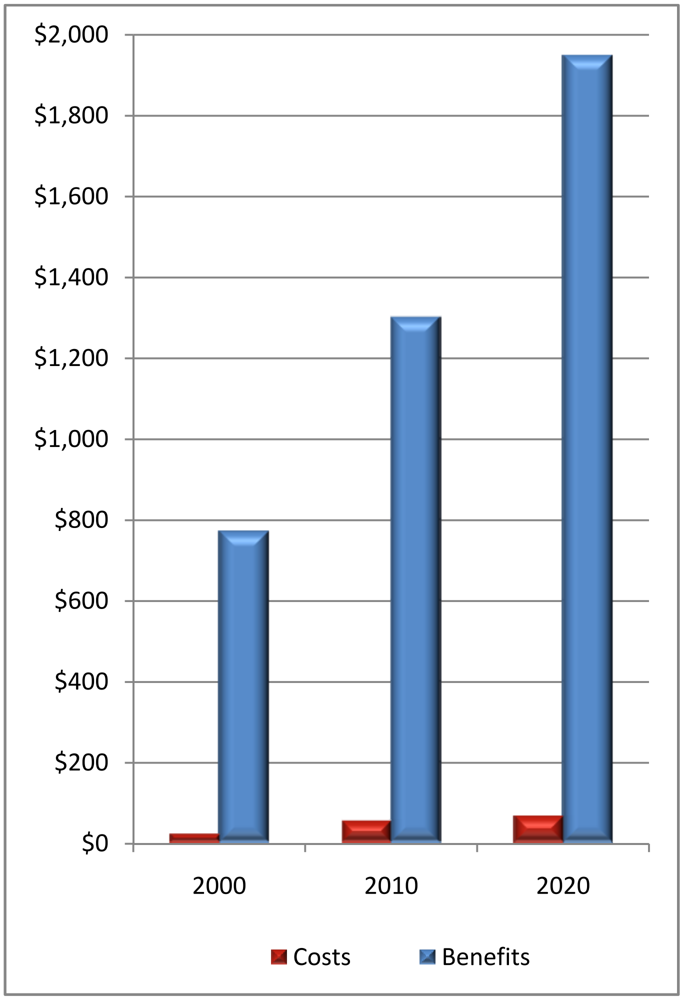

Exhibit 1. Primary Central Estimates of direct benefits and direct costs for the 2000, 2010, and 2020 study target years. (In billions of 2006 year value dollars).

- Beyond the direct value people assign to the health and environmental improvements they gain, 1990 Clean Air Act programs are projected to improve U.S. economic growth and the economic welfare of American households as better health leads to greater worker productivity and savings on medical expenses for air pollution-related health problems.

- The most significant known human health effects from exposure to air pollution are associated with exposures to fine particulate matter and ground-level ozone pollution. Many of these effects could be quantified for this study; but other health effects of particulate matter and ozone, health effects associated with other air pollutants, and most air pollution-related environmental effects could be quantified only partially, if at all.

- The limits in available data and modeling tools to address other health and environmental consequences of air pollutant exposure implies there is an ongoing need for investment in research to improve the coverage of potentially important effects in benefit-cost studies of air pollution programs, because not all EPA programs are targeted on reducing particulate matter and ozone exposures. Additional research also is needed to reduce uncertainties in the estimates of included effects, especially uncertainties associated with estimating particulate matter- and ozone-related mortality and the economic value of avoiding those outcomes.

- To improve their usefulness to policymakers and the public, future air pollution policy analyses could be designed to provide insights on the combined effects of programs to address greenhouse gas emissions and programs currently implemented under the Clean Air Act.

- Consideration should be given to improving macroeconomic modeling of major environmental programs so their economic benefits as well as their financial costs are reflected in projections of how these programs might affect the overall economy and the economic welfare of American households.

About this Report

This report is the third in a series of EPA studies which estimate and compare the benefits and costs of the Clean Air Act and related programs.

The first report was called the Retrospective Study, and it was published in 1997. This first study estimated the benefits and costs of programs implemented pursuant to the 1970 Clean Air Act and the 1977 Amendments, and included an analysis of the benefits and costs of phasing out leaded gasoline.

The second report was called the First Prospective Study. Published in 1999, it evaluated the incremental benefits and costs of the 1990 Clean Air Act Amendments and associated programs through the year 2010, relative to controls in place as of 1990. In addition to evaluating the effects on human health, the economy, and the environment of Titles I through V of the 1990 Amendments, the First Prospective Study analyzed the benefits and costs of phasing out stratospheric ozone depleting chemicals such as chlorofluorocarbons (CFCs) under Title VI.

The current report is called the Second Prospective Study. This new study updates and expands the First Prospective Study by using new and better data and modeling tools. The new study also looks out further into the future by evaluating and costs and benefits of 1990 Amendment programs through the year 2020.

The Second Prospective Study focuses on evaluating the significant changes made over the last decade in the implementation of Titles I through IV. Readers interested in benefit and cost information related to Title V (permits) and Title VI (stratospheric ozone protection) are referred to the First Prospective Study and subsequent Regulatory Impact Analyses.

Goals and Objectives of the Study

During the legislative efforts leading up to enactment of the 1990 Clean Air Act Amendments, members of Congress working on the Act's reauthorization made it clear they wanted more and better information from EPA about the economic, health, and environmental effects of air pollution control programs. To ensure this improved information was available to support future policymaking, Congress added statutory language which required EPA to conduct periodic studies to evaluate the benefits and costs of the Clean Air Act itself. Enhanced credibility and continual improvement in data and methods were promoted by requiring that the design, implementation, and results of each study were to be reviewed by a multidisciplinary panel of outside experts.

To meet Congress' goals for the third study in this series of Clean Air Act benefit-cost analyses, EPA defined a central objective and three supplemental objectives. Consistent with the central objectives defined for the two preceding studies, the current

CLEAN AIR ACT SEC. 312. ECONOMIC IMPACT ANALYSES (as amended, in part):

(a) The Administrator…shall conduct a comprehensive analysis of the impact of this Act on the public health, economy, and environment of the United States…

(b) In describing the benefits of a standard described in subsection (a), the Administrator shall consider all of the economic, public health, and environmental benefits of efforts to comply with such standard…

The Administrator shall assess how benefits are measured in order to assure that damage to human health and the environment is more accurately measured and taken into account…

(c) [T]he Administrator shall consider the effects…on employment, productivity, cost of living, economic growth, and the overall economy of the United States.

(e) [T]he Administrator…shall appoint an Advisory Council on Clean Air Compliance Analysis of…recognized experts in the fields of the health and environmental effects of air pollution, economic analysis, environmental sciences, and such other fields that the Administrator determines to be appropriate.

(g) The Council shall-

(1) review the data to be used for any analysis required under this section and make recommendations to the Administrator on the use of such data;

(2) review the methodology used to analyze such data and make recommendations to the Administrator on the use of such methodology; and

(3) prior to the issuance of a report…review the findings of such report, and make recommendations to the Administrator concerning the validity and utility of such findings.

Exhibit 2. 1990 Clean Air Act Section 812 statutory language -- abridged.

study is designed to estimate the direct costs and direct benefits of the Clean Air Act, including the major federal, State, and local programs implemented to meet its requirements. The present study focuses on estimating the incremental effects of the 1990 Amendments in particular, and covers the period from 1990 –when these most recent Amendments were passed—through the year 2020.

A second, subsidiary objective of the study was to gauge the economy-wide effects of the 1990 Clean Air Act programs, including evaluation of the Act's effects on the overall growth of the U.S. economy and the economic well-being of American households.

EPA also sought to be as comprehensive as possible –subject to practical limitations imposed by budget and information constraints—by considering a wide range of human health, human welfare (i.e., quality of life), and ecological effects. While some of these effects may contribute only minimally, if at all, to the quantitative estimates of benefits and costs generated for this study, looking at a broad range of effects was intended to ensure that (a) effects of concern to various stakeholders were included and (b) EPA and outside researchers could obtain additional insights about deficiencies in the scope and quality of current information.

A fourth and final objective of the current study was to assess its limitations and uncertainties to identify opportunities for improving data and methods, and to explore the need for refining the scope and design of future air pollution benefit-cost studies. External peer review by the outside experts serving on the Council was a critical aspect of efforts to meet this objective, as well as the other objectives of this study.

Study Design

The current study is similar to the previous two efforts in its fundamental design. To isolate the effects of Clean Air Act programs, the study configures and compares two alternative states of the world: one with the 1990 Clean Air Act Amendments, and one which assumes the amendments were not passed.

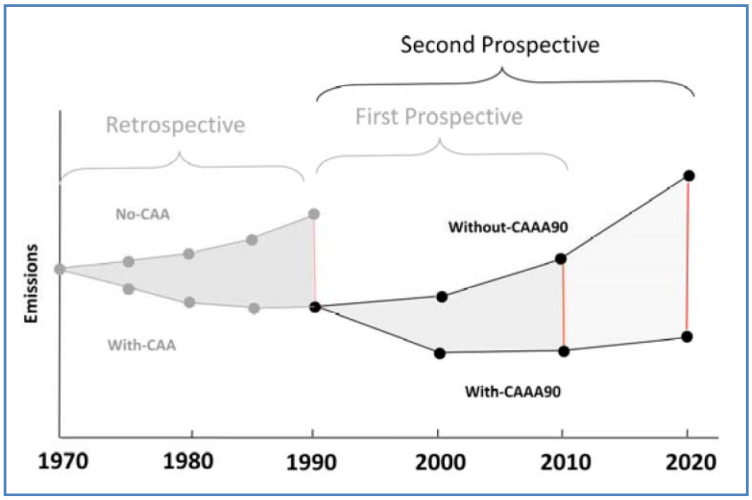

Exhibit 3. Second Prospective Study scenarios conceptual schematic.

In particular, the first scenario was built to reflect the actual history of post-1990 Clean Air Act implementation, including known programs already established, and future programs and control strategies anticipated in the later years of the study period. This scenario was called the “with 1990 Clean Air Act Amendments scenario”, or *With-CAAA90* case for short, and it represents a world of lower emissions but higher costs following enactment of the 1990 Amendments. The *With-CAAA90* case is represented by the lower line in Exhibit 3, which depicts a not-to-scale schematic illustrating the scenarios analyzed.

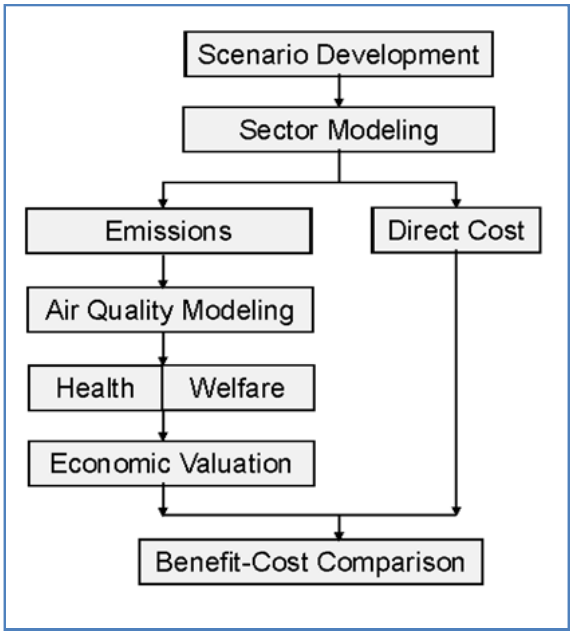

Exhibit 4. Analytical sequence.

The second, contrasting scenario reflects a hypothetical world which assumes federal Clean Air Act and related programs were frozen as of November 1990. This is the month the amendments were actually passed, so 1990 serves as the “base year” of the analysis when the two scenarios are initially set as equal but then begin to diverge. The counterfactual scenario was called the “without 1990 Clean Air Act Amendments scenario”, or *Without-CAAA90* case. The hypothetical *Without-CAAA90* case is represented in Exhibit 3 by the upper 1990 to 2020 trend line showing the higher emissions which would result if standards stayed fixed but the economy and the population of the U.S. grew over the 1990 to 2020 period.

Once they were configured, the *With-CAAA90* and *Without-CAAA90* scenarios were processed through a series of economic and physical effects models, and their differences were estimated and compared. Specifically, each scenario was analyzed using a sequence of models to estimate what pollution control measures were (or might be) taken by government, private industry, and individuals; and what the effects of those measures might be in terms of economic and environmental change. The sequence of modeling steps followed to analyze the two scenarios is shown in Exhibit 4. Detailed descriptions of each analytical step –including the particular data, models, and methodologies used and their attendant uncertainties—are provided in the full integrated report and supporting technical documents.

One consequence of this sequential modeling approach is that the scenarios were defined early in the study. As such, this study reflects a particular snapshot in time with respect to known and anticipated control programs, especially those incorporated in the *With-CAAA90* scenario. Several important programs, however, have been initiated or revised since the analytical scenarios were locked for the study. For example, the *With-CAAA90* scenario reflects the Clean Air Interstate Rule (CAIR) which had been recently promulgated when the scenarios were set, but this rule is now being replaced by an alternative transport rule. Readers are encouraged to consult the relevant Regulatory Impact Analyses for information on the estimated benefits and costs of recent rules.

To ensure high quality, credible results, the study used the best available data and state of the art modeling tools and methodologies. Most important, the design of the study, many of the intermediate methodological choices and findings, and the final results and their interpretation were all reviewed by the Advisory Council on Clean Air Compliance Analysis –hereafter, the Council—and its three technical subcommittees. The specialized expert review of the emissions and air quality, human health effects, and ecological effects study components by the three technical subcommittees complemented and supported the Council's broad expertise and its own specialized expertise in economics.

Primary Results

Direct Cost

Compared to the baseline scenario without the 1990 Clean Air Act and related programs, the *With-CAAA90* scenario adds controls across five major categories of emission sources. All significant emissions sources are assigned to one of these five major source categories. Two of these categories cover stationary point sources of emissions, two cover mobile sources, and the fifth category covers smaller sources dispersed over wide areas. The categories are:

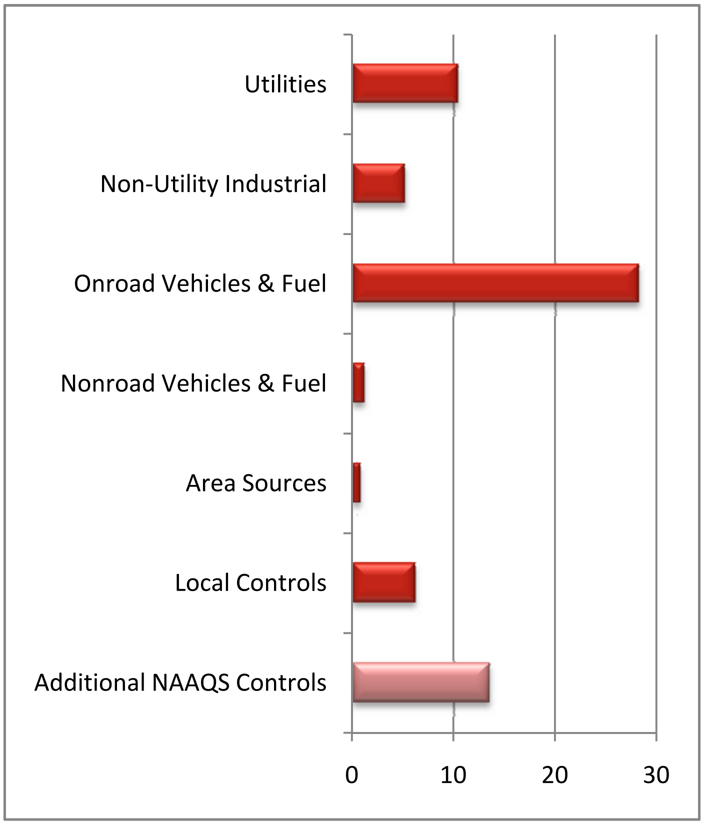

Exhibit 5. Year 2020 direct cost by source category. (In billions of year 2006 value dollars)

1. **Electricity generating units** (e.g., coal-fired powerplants)
2. **Non-utility industrial sources** (e.g., industrial boilers, cement kilns)
3. **Onroad vehicles and fuel** (e.g., cars, buses, trucks)
4. **Nonroad vehicles and fuel** (e.g., aircraft, construction equipment)
5. **Area sources** (e.g., wildfires, construction dust, dry cleaners)

The costs incurred to reduce emissions from these sources under the 1990 Clean Air Act are estimated to rise steadily throughout the 1990 to 2020 study period. By 2020, the study target year when differences between the *With-CAAA90* and *Without-CAAA90* scenarios are at their greatest, additional annual compliance expenditures are estimated to be about $65 billion (in year 2006 value dollars).

As shown in Exhibit 5, these incremental costs of compliance did not fall evenly across the five major source categories. Almost half of the year 2020 direct costs are to meet requirements for onroad vehicles and the fuels used to operate them. About 40% of the $28 billion in onroad expenditures is to meet fuel composition requirements and the rest is incurred to meet tailpipe standards and implement vehicle inspection and maintenance programs.

Electric utilities account for the second largest area of expenditure, with costs in the year 2020 equal to a little over $10 billion. The programs leading to the bulk of these expenditures include the Title IV acid rain sulfur dioxide allowance trading program, the Clean Air Interstate Rule (CAIR), programs targeted at reducing nitrogen oxide emissions (e.g., the NOx SIP Call), and controls required to meet the national ambient air quality standards for particulate matter and ozone.

Implementation of federal and regional control programs to meet the national particulate matter and ozone standards accounts for much of the cost incurred by the five major emissions source categories. However, for many local areas, emissions reductions achieved by these programs are not sufficient to reach attainment with national air quality standards. Under the Clean Air Act, these local areas are required to implement additional controls tailored to their particular needs and opportunities for the further emission reductions needed to improve air quality to healthful levels. Additional local controls might therefore apply to one or more of the five major source categories. Expenditures for local controls which could be identified as both suitable for a given location and cost-effective to implement were estimated to reach about $6 billion by 2020.

By the year 2020, however, the particular challenge of reaching the 8-hour National Ambient Air Quality Standard (NAAQS) for ozone in some locations is significant. Under the particular *With-CAAA90* scenario analyzed in this study, even the additional local controls described above which apply identified, cost-effective technologies are insufficient to improve modeled ozone air quality to levels consistent with NAAQS attainment. Since additional cost-effective local controls using current technologies could not be identified, the estimated costs of the additional measures these local areas may implement is highly uncertain. The *With-CAAA90* scenario adopts an assumption that the additional emissions reductions needed beyond those achieved by identified control measures will cost $15,000 per ton, a figure which could turn out to be too high or too low depending on local circumstances and the prospects for near-term improvements in control technologies and cost. The total incremental cost of these additional local controls using unidentified technologies is estimated to be $13 billion, but this estimate is so uncertain that it is reported as a subtotal separate from the identified control measures subtotal of $52 billion.

Emissions Reductions

Though the controls applied across the major categories of emissions sources were costly, they achieved substantial reductions in emissions contributing to ambient concentrations of particulate matter, ozone, and other air pollutants. The full range of emissions reductions estimated under the *With-CAAA90* case and the breakdown by source category are described in the full report, but the overall reductions in pollutants which contribute most to changes in particulate matter and ozone are highlighted in Exhibit 6. In addition to directly emitted fine particles, three other pollutants contribute to increases in ambient concentrations of fine particles through secondary formation and transport in the atmosphere. For example, gaseous sulfur dioxide can be transformed in the atmosphere to particulate sulfates. Hydrocarbons and nitrogen oxides are also key pollutants contributing to the formation of ground-level ozone.

The estimated reductions in these pollutants achieved as of 2020 under the *With-CAAA90* case are large for two reasons: they reflect both absolute reductions relative to 1990 base year conditions and avoided increases in emissions which result under the *Without-CAAA90* case when standards stay fixed at 1990 levels but economic activity increases from 1990 to 2020. Approximately 75 percent of the 2020 emissions reductions are attributable to improvements relative to 1990, while the remaining 25 percent is attributable to avoiding increases in emissions that could have resulted if Clean Air Act standards stayed fixed while population and economic activity grew.

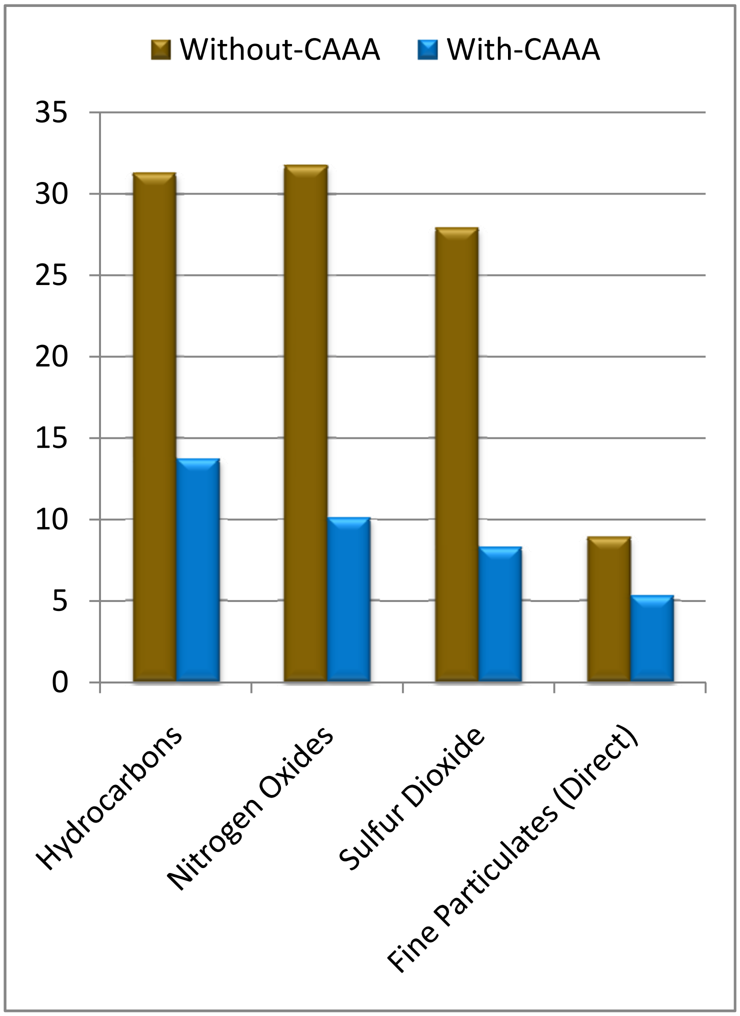

Exhibit 6. Year 2020 key pollutant emissions under the *With-CAAA90* and *Without-CAAA90* scenarios. (In millions of short tons)

Most of the reduction in volatile organic compounds (VOCs) or hydrocarbons is achieved by controls on evaporative emissions from area sources (e.g., household solvents), tailpipe and evaporative emission from vehicles and nonroad engines, and non-utility industrial sources.

For nitrogen oxide (NOx) emissions, all five major source categories achieve emissions reductions under the *With-CAAA90* scenario; but the most substantial contributions to lower emissions are attributable to tailpipe standards for onroad vehicles and reductions achieved by utilities subject to cap and trade programs and/or the Clean Air Interstate Rule. Requirements related to the national standards for fine particulate matter also reduce NOx emissions.

Utilities are also the source category which achieves the most significant reductions in sulfur dioxide (SO2) emissions, accounting for about 75 percent of the total reduction achieved in 2020. Cap and trade programs, CAIR, and other control programs implemented pursuant to the national particulate matter standards account for most of the difference in sulfur dioxide emissions estimated between the *With-CAAA90* and *Without-CAAA90* scenarios.

About 40 percent of the year 2020 reduction in directly emitted fine particles is achieved by controls on area sources such as construction dust and residential woodstoves. Reductions from utilities and from nonroad and onroad sources also contribute significantly toward meeting the requirements of the national ambient air quality standards for particulate matter.

Air quality improvements

The substantial reductions in emissions contributing to ambient concentrations of ozone and fine particulate matter lead to significant differences in modeled air quality conditions under the *With-CAAA90* and *Without-CAAA90* scenarios.

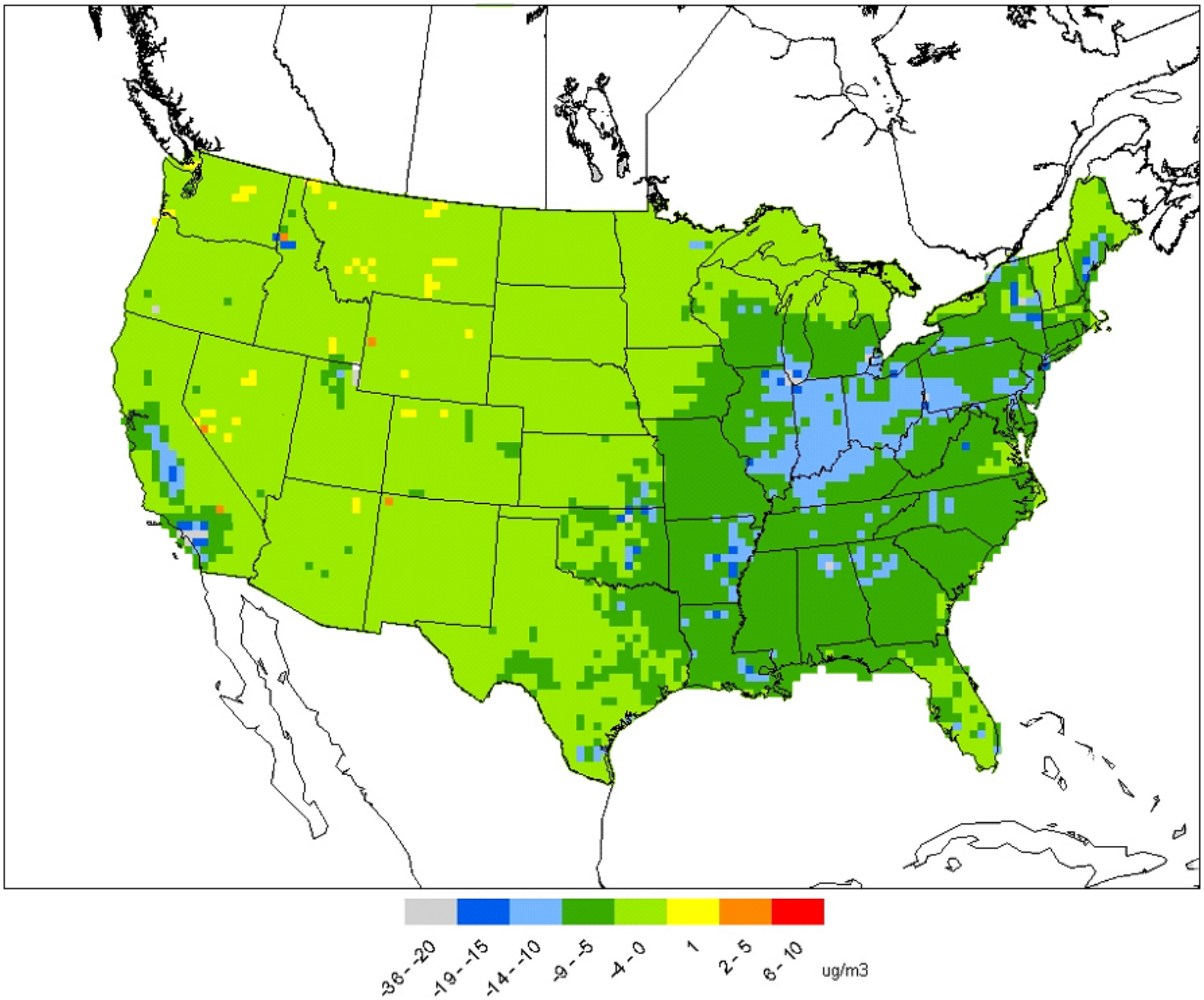

Exhibit 7. Difference in annual average fine particle (PM2.5) concentrations between the *With-CAAA90* and *Without-CAAA90* scenarios: *With-CAAA90* minus *Without-CAAA90* for 2020. (In micrograms per cubic meter).

Air quality modeling results for all pollutants and target years analyzed in this study are available in the full report, but Exhibit 7 highlights the estimated change in fine particle concentrations between the *With-CAAA90* and *Without-CAAA90* cases. The particulate matter differences are worth emphasizing because reductions in fine particle exposures are responsible for the vast majority of the benefits which could be evaluated in economic terms for this study.

Exhibit 7 indicates that reductions in fine particle concentrations are large and widespread, particularly in California and the Eastern U.S., especially the Ohio Valley region. Because these areas had relatively high particulate matter concentrations in the 1990 base year, the modeling results imply that 1990 Clean Air Act programs were effective in targeting high emissions sources, especially those affecting population centers where improvements in air quality would benefit the greatest number of people. There are a few locations in the West where fine particle concentrations are estimated to be slightly higher in 2020 under the *With-CAAA90* scenario, but these isolated spots of small disbenefit represent increases of less than 1 microgram per cubic meter. Investigation of these small disbenefits indicated that they primarily arise due to increases in electricity generation by Western powerplants which burn low-sulfur coal. Overall, the principal outcome demonstrated by Exhibit 7 is the breadth and magnitude of reductions in fine particle concentrations across the 48 States under the *With-CAAA90* case.

Ozone concentrations are also significantly lower under the *With-CAAA90* scenario relative to the *Without-CAAA90* scenario, both in the West as shown in Exhibit 9; and across the East as shown in Exhibit 8. The patterns of air quality improvements for ozone shown in Exhibit 9 and Exhibit 8 are similar to those observed in Exhibit 7 for fine particles: widespread regional improvements across the East, with improvements in the West occurring predominantly in areas influenced by Southern California population centers.

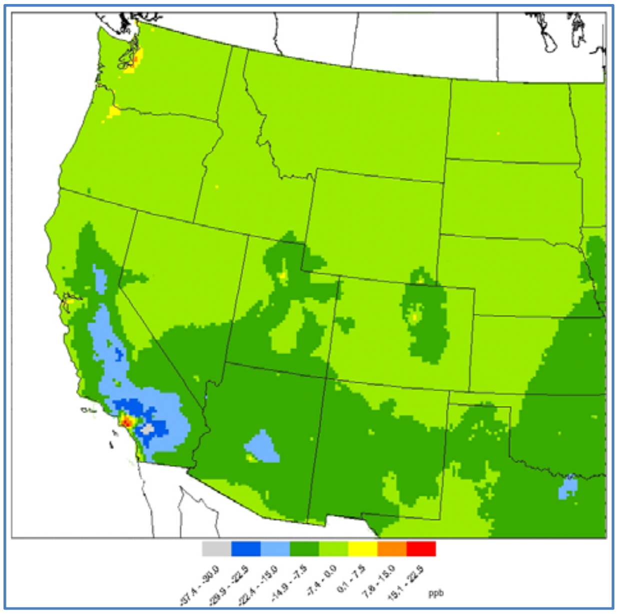

Exhibit 9. Difference in simulated daily maximum 8-hour ozone concentration for the Western US CMAQ domain for the August 15 episode day: *With-CAAA90* minus *Without-CAAA90* for 2020. (In parts per billion).

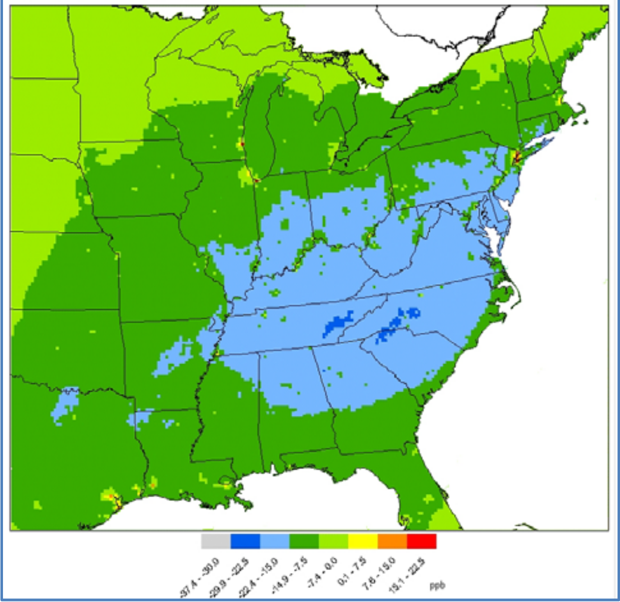

Exhibit 8. Difference in simulated daily maximum 8-hour ozone concentration for the Eastern US CMAQ domain for the July 15 episode day: *With-CAAA90* minus *Without-CAAA90* for 2020. (In parts per billion).

Health Improvements

The steady improvements in air quality estimated under the *With-CAAA90* case from 1990 to 2020 period lead to increasing health and environmental benefits over the entire study period. By 2020, the last year analyzed in this study, the differences in air quality and human health outcomes between the *With-CAAA90* and *Without-CAAA90* scenarios are substantial.

As discussed above and illustrated in Exhibit 7, the most significant reductions in fine particle concentrations are achieved in areas with relatively poor air quality and/or high population density. This result is due in large part to the effective design of federal, State, and local programs aimed at meeting ambient air quality standards in ways which maximized public health improvements. The effectiveness of these programs in achieving well-targeted reductions in exposure means that the differences in health outcomes between the *With-CAAA90* and *Without-CAAA90* scenarios are substantial, even dramatic. For example, as early as 2000, annual average exposures to fine particles among the U.S. population are lower by an average of 5 micrograms per cubic meter under the *With-CAAA90* scenario. By 2020, this population-weighted, annual average exposure difference between the scenarios increases to an estimated 9 micrograms per cubic meter, all as a result of programs related to the 1990 Clean Air Act Amendments.

Health Effect Reductions (PM2.5 & Ozone Only)	Year 2010	Year 2020
PM2.5 Adult Mortality	160,000	230,000
PM2.5 Infant Mortality	230	280
Ozone Mortality	4,300	7,100
Chronic Bronchitis	54,000	75,000
Acute Bronchitis	130,000	180,000
Acute Myocardial Infarction	130,000	200,000
Asthma Exacerbation	1,700,000	2,400,000
Hospital Admissions	86,000	135,000
Emergency Room Visits	86,000	120,000
Restricted Activity Days	84,000,000	110,000,000
School Loss Days	3,200,000	5,400,000
Lost Work Days	13,000,000	17,000,000

Exhibit 10. Differences in key health effects outcomes associated with fine particles (PM2.5) and ozone between the *With-CAAA90* and *Without-CAAA90* scenarios for the 2010 and 2020 study target years. (In number of cases avoided, rounded to 2 significant digits).

The most significant outcome among those listed in Exhibit 10 is the large reduction in risk of premature mortality associated with fine particulate matter. Ozone health studies also indicate there is a separate, additive contribution to reduced premature mortality risk from this pollutant beyond the premature mortality effect associated with fine particle exposures. This study's estimates for these incidence reductions are based on a strong and extensive foundation of peer-reviewed epidemiological literature. The methodologies used to apply these epidemiological studies to the estimation of reduction in population risks from particulate matter and ozone exposure have also been extensively peer-reviewed.

In addition to reductions in incidences of premature mortality, reductions in exposure to fine particles and ozone are also estimated to achieve major reductions in serious diseases such as chronic bronchitis and acute myocardial infarction, as well as fewer hospital admissions, emergency room visits, lost work, and lost school days.

Controls on emissions of hazardous air pollutants, including heavy metals and toxic gases, are known to reduce adverse health effects, though data and tools to quantify the full extent of the reductions in health risks from these pollutants are limited. A case study assessing the effects of the 1990 Clean Air Act in reducing benzene emissions and exposures in the Houston area was conducted as part of this study. The case study found a significant cancer-reducing benefit from 1990 Clean Air Act Amendment programs overall in the region, but also found that 1990 Amendment programs led to the most substantial reductions in those areas with the highest baseline cancer risks. These results are described in greater detail in the full report and in a separate technical report documenting the Houston benzene case study.

Reductions in ambient concentrations of other criteria pollutants such as carbon monoxide also confer health benefits, though many of these benefits are difficult to quantify for various reasons. For example, in the case of carbon monoxide, available health studies are not well suited to isolating the incremental contribution of carbon monoxide reductions to improved health when significant reductions in other pollutants, such as particulate matter, are modeled at the same time. Furthermore, some criteria pollutant health effects can be quantified in physical terms but economic studies supporting valuation of the changes in physical outcomes are unavailable. Whether the limits on quantification of these other criteria pollutant effects emerge at the physical effect or economic valuation step, the result is that these effects are not reflected in the Primary Estimates of health improvements presented in this report.

Other Benefits to People and the Environment

Beyond the direct health benefits of Clean Air Act programs, a variety of other improvements to human well-being and ecological health are assessed in this study. Efforts to evaluate these other “non-health” effects were motivated by the study’s goal of providing insights on the full range of outcomes which may affect people and the environment, including those which might either be important to particular stakeholders or warrant further research to support more or better quantitative treatment in future studies.

The first step in this study’s assessment of non-health effects was a literature survey to identify ecological effects of Clean Air Act-related pollution reductions at various levels of biological organization (e.g., ecosystem, community, individual, cellular). The range of potentially relevant effects found in this literature review is described in the full report and supporting technical documents. Based on the results of this broad assessment, the analysis was then narrowed to focus on those ecological and human health effects for which economic valuation information was available and could be applied. This narrowing of focus served the principal goal of the study, which was to evaluate the various health, economic, and environmental effects of the Clean Air Act using comparable measures of value. In the end, only a very limited number of non-health effects could be included in the Primary Estimate of benefits, and these quantified and monetized ecological and welfare effects are listed in Exhibit 11.

In addition to limitations in the range of effects included in the Primary Estimate results, several of the included effects were subject to limitations in geographic coverage or the number of commodities or ecosystems covered. Relevant limitations are listed in parentheses following each quantified endpoint in Exhibit 11. For example, available data and modeling tools supported assessment of the effects of changes in ozone exposure only for commercially important crops and tree species; and other effects such as changes in recreational fishing opportunities due to acidic deposition could only be addressed through case study examinations not suitable for extrapolation to the other areas of the country. This study therefore suffers from the same persistent limitations on data and methods for evaluating potentially important ecological and human welfare outcomes which have plagued other benefit-cost studies of air pollution control programs. The consequence is ongoing uncertainty about the potential magnitude of these effects relative to the human health effects which can be more readily evaluated in terms of physical outcomes and changes in economic value.

Quantified Human Welfare and Ecological Effects

Visibility in residential areas (metropolitan areas)
Visibility in recreational areas (large parks in three regions)
Commercial timber (commercially important tree species)
Agriculture (commercially important crops)
Recreational fishing (Adirondacks)
Materials damage (a few acid-sensitive materials)

Exhibit 11. Ecological and Welfare Effects included in Primary Estimate of Benefits.

Visibility

One particular non-health effect of better air quality under the *With-CAAA90* scenario is worth highlighting: improved visibility. This study applies a new methodology for estimating the economic value of visibility improvements in metropolitan areas, and the effect of this new approach is to expand the number of locations where visibility improvements can be valued in economic terms. The significance of the results obtained using this new methodology highlights the importance of improved visibility for enhanced quality of life.

There are two types of visibility improvement benefits estimated in this study: recreational visibility and residential visibility. Recreational visibility benefits reflect the values people assign to reductions in obscuring haze and resulting improvements in scenic views at important U.S. recreational areas, such as the Grand Canyon. Residential visibility benefits capture the value people assign to improved visibility where they live.

The differences in air pollution-related visibility impairment under the *With-CAAA90* and *Without-CAAA90* scenarios used to estimate both recreational and residential visibility benefits are shown in Exhibit 12. While benefits are estimated for all target years of the study, Exhibit 12 shows the estimated county-level improvements in visibility under the *With-CAAA90* case relative to the *Without-CAAA90* case for the year 2020. Improvements are measured in Deciviews, which is a rating scale aimed at measuring and then valuing perceptible changes in visibility.

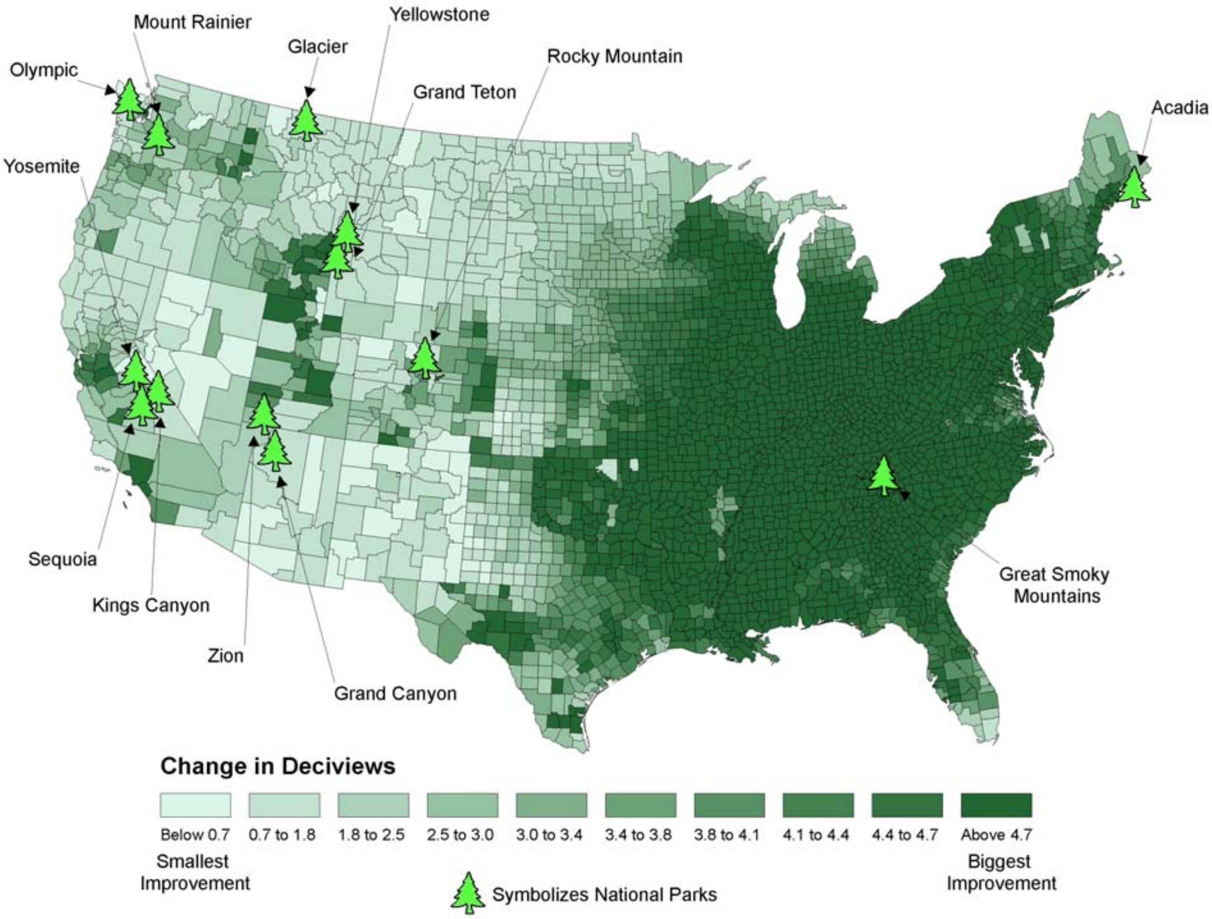

Exhibit 12. Differences in visibility at the county level between the *With-CAAA90* and *Without-CAAA90* scenarios for 2020.

Previously established methods were used to estimate the value of the visibility improvements at the recreational areas shown in Exhibit 12. Visibility improvements in these "Class I" recreational areas are estimated to reach $18 billion by the year 2020. Applying the new methodology supporting expanded coverage of U.S. metropolitan areas, residential visibility benefits are estimated to reach $49 billion in 2020, a number which is significant but consistent with the substantial improvements in visibility across major population centers depicted in Exhibit 12. The $67 billion combined total for residential and recreational visibility benefits in the year 2020 slightly exceeds the entire $65 billion estimated cost of 1990 Clean Air Act compliance for that year.

Comparison of Direct Costs and Direct Benefits

The final step in the benefit-cost analysis conducted for this study is to express the various health, welfare, and environmental benefits of 1990 Clean Air Act programs in dollar values so the benefits can be compared to the dollar-based estimates for control costs. As described above, many of these beneficial outcomes cannot be expressed in terms of economic value because the scientific and economic studies to support such valuations are either inadequate or unavailable. For those effects which could be converted to measures of economic value, important uncertainties or limitations remain.

Some who consider these uncertainties and other limitations of benefit-cost analysis may prefer to use other paradigms for measuring, comparing, and evaluating the outcomes projected by this study. For example, some may prefer not to attempt to assign uncertain dollar-based values to changes in risk of premature mortality, preferring instead, for example, to compare the costs of Clean Air Act programs with the number of avoided incidences of premature mortality or illness they achieved.

The full report for this study and the supporting technical documents provide details about the estimated benefits achieved in terms of physical outcomes as well as the estimated economic value of those outcomes, and these detailed results can be used to support alternative assessments of value.

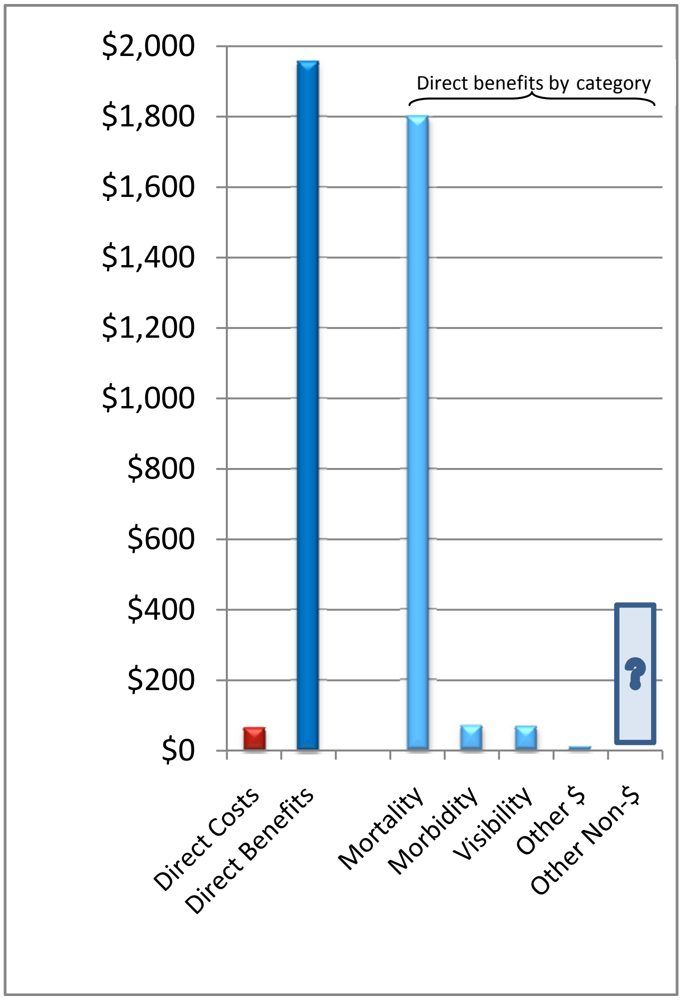

Exhibit 13. Year 2020 Primary Central Estimates of direct costs and direct benefits with breakdown of benefits by effect category. (In billions of year 2006 dollars).

One example of an alternative paradigm for assessing and comparing the value of premature mortality risk reductions achieved by the 1990 Clean Air Act programs is to divide compliance costs for a given year by the number of incidences of avoided premature mortality achieved by that year's emissions reductions. The result of this calculation for *With-CAAA90* emission reductions achieved in the year 2020 is about $275,000 per avoided incidence. This and similar calculations, however, must be interpreted cautiously because cost-effectiveness comparisons typically divide costs by an effectiveness measure for a single beneficial outcome. Using the current example, comparing costs only to reductions in incidences of premature mortality may result in a failure to account for other potentially important benefits such as improved ecosystem protection, especially when improvements ancillary to the cost-effectiveness calculation cannot be quantified and then netted out of the cost side of the equation.

While this study provides data supporting various approaches for evaluating Clean Air Act program outcomes, a central objective of the study was to estimate the net economic benefit (i.e., quantified direct benefits minus quantified direct cost) of differences between the *With-CAAA90* and *Without-CAAA90* scenarios. The separate totals for benefits and costs were reported earlier based on rounding to two significant digits to avoid creating an undue impression of precision in the estimates. The specific outcomes for the year 2020 are direct costs of $65 billion and direct benefits of $2,000 billion (i.e., $2 trillion). Prior to rounding to two significant digits for reporting purposes, the benefit estimate is $1,951 billion. Subtracting the $65 billion in direct costs from $1,951 billion in direct benefits results in a net benefit estimate of $1,886 billion, which resolves to a two significant digit estimate of $1,900 billion (in year 2006 value dollars).

Comparison of First Prospective Study and Second Prospective Study benefit estimates for the year 2010.

The previous study in this series of reports, the First Prospective Study, was published in 1999. Since then, significant improvements have been made in air pollution-related benefit-cost analysis data and methods, especially those associated with the fine particulate matter and ground-level ozone pollutants which are the focus of the present study. Insights about the significance of these methodological changes can be gained by comparing the results of the current study with those of the previous study for the year 2010, a key target year common to both analyses.

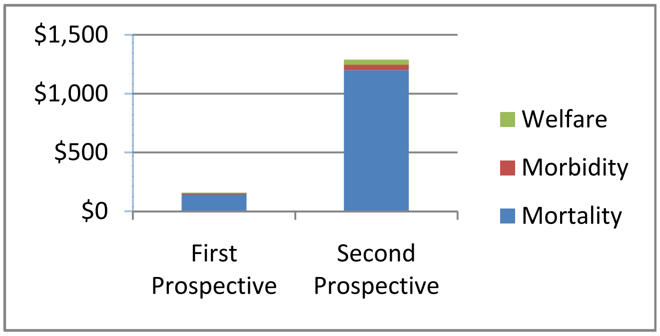

Exhibit 14. Comparison of 2010 Benefits from First and Second Prospective Studies. (In billions of year 2006 value dollars)

As shown in Exhibit 14, benefits estimates for all three main categories of effect are significantly higher for the current study. There are several reasons these differences are so significant. Some of the difference results from the addition of several new and important control programs implemented since 1999, including the Clean Air Interstate Rule and major programs to reduce onroad and nonroad emissions. Welfare and morbidity effects are also higher because of the addition of new endpoints, such as improvements in residential visibility and reductions in acute myocardial infarctions. Air quality models have also been significantly improved since 1999, allowing analysis of fine particle species such as secondary organic aerosols which had been omitted in the First Prospective Study. The most influential change, however, appears to result from updates over the last decade in the epidemiological studies which provide estimates of changes in population risk of premature mortality associated with exposure to fine particulates.

Avoiding incidences of premature mortality, especially those associated with exposure to fine particulate matter, contributes the vast majority of the direct benefits of 1990 Clean Air Act programs measured in dollar value terms, as shown in Exhibit 13. There are two principal reasons mortality effects dominate the estimated differences in value between the *With-CAAA90* and *Without-CAAA90* cases. First, as described above in the section on health improvements, the differences in air quality, human exposure, and resulting risk of premature mortality between the two scenarios are substantial, but are based on an extensive literature and peer-reviewed methods. Second, these changes in risk of premature mortality are estimated to have significant economic value, as measured by studies which assess what people are willing to pay to reduce such risks. The methods used in this study for valuing reductions in risk of premature mortality are consistent with the methods used in the two prior studies in this series, are consistent with prevailing default values described in longstanding EPA economic guidelines, and are consistent with recent EPA Regulatory Impact Analyses. The valuation estimates used herein are also fairly consistent with literature which is more recent than the literature used as the foundation for the longstanding methods applied here. However, the appropriate value to assign to premature mortality risk reductions achieved through air pollution control remains an area of significant uncertainty as discussed further below and in this study's full report and detailed technical documents.

Other categories of benefits presented in Exhibit 13 include total morbidity effects, visibility improvements, other welfare and ecological effects which could be expressed in terms of dollar values, and other welfare and ecological effects which were not quantified and monetized in the Primary Estimates of benefits for this study. This last category of benefits is presented as a question mark in Exhibit 13 to emphasize that the potential contribution to total benefits of these unquantified effects is simply unknown, but could conceivably be substantial.

While the principal message conveyed by Exhibit 13 is the extent to which mortality reduction benefits far exceed all other effects, it is also noteworthy that morbidity reduction benefits and visibility improvement benefits are each roughly comparable to direct costs. This implies that either of these benefit categories alone might justify the direct costs of compliance from an economic standpoint, even if mortality reduction and all other known and unknown benefits are disregarded.

Economy-Wide Effects

The main results of this study are the direct benefits of 1990 Clean Air Act programs relative to the direct costs of those programs. However, some public policy programs have such significant economic effects that they can influence the levels and patterns of activity across the larger economy, and it can be important to assess these broader economic consequences. The differences between the *With-CAAA90* and *Without-CAAA90* scenarios modeled in this study were expected to manifest these types of large, "spillover" effects on important sectors of the economy due, for example, to the potential effects of higher electricity prices under the *With-CAAA90* case on sectors which are major consumers of electricity. Therefore, a model of the overall economy was configured and run to estimate how the size and structure of the economy might be different under the two scenarios analyzed.

The first set of macroeconomic model runs followed the customary practice of altering only cost-side effects, in this case the effects of diverting significant resources toward air pollution control and away from other potential economic uses of those resources. In particular, the macroeconomic model was configured to assess the effects of larger investments in air pollution control under the *With-CAAA90* scenario on prices and quantities of goods and services produced and consumed by different sectors, including households and various categories of industrial activity.

The full set of modeling results, including the changes in output from each of the economic sectors covered by the EMPAX macroeconomic model, are presented in the full report and supporting technical document; but the key results of the "Cost-Only" runs are shown in Exhibit 15. These key effects include changes in overall economic growth through the year 2020 as a result of investments made in Clean Air Act programs between 1990 and 2020; and the effect of economic changes on a particular measure of the economic welfare of households. Specifically, the results for the "Cost-Only" run show that economic growth –as measured by Gross Domestic Product (GDP)—is about 0.54% lower in the year 2020 under the *With-CAAA90* scenario than under the *Without-CAAA90* scenario, mostly due to the effects of higher energy costs on various sectors of the economy.

The estimated reduction in the economic welfare of households in 2020 is about 0.39%, which is smaller than the reduction in GDP due to adjustments made by households which offset the adverse effect of reductions in household consumption of goods and services. The dollar equivalent of this 0.39% reduction in household welfare is about $75 billion.

The implication of the "Cost-Only" macroeconomic modeling is that 1990 Clean Air Act programs both shrank the economy relative to what it would have been without these programs, and caused the average household to be worse off, at least as measured in the limited "economic efficiency" terms reflected in the macroeconomic model's measure of household welfare.

However, in reality effective air pollution control programs do not simply impose costs on the economy. They also improve air quality, which in turn affects the health and productivity of workers, reduces

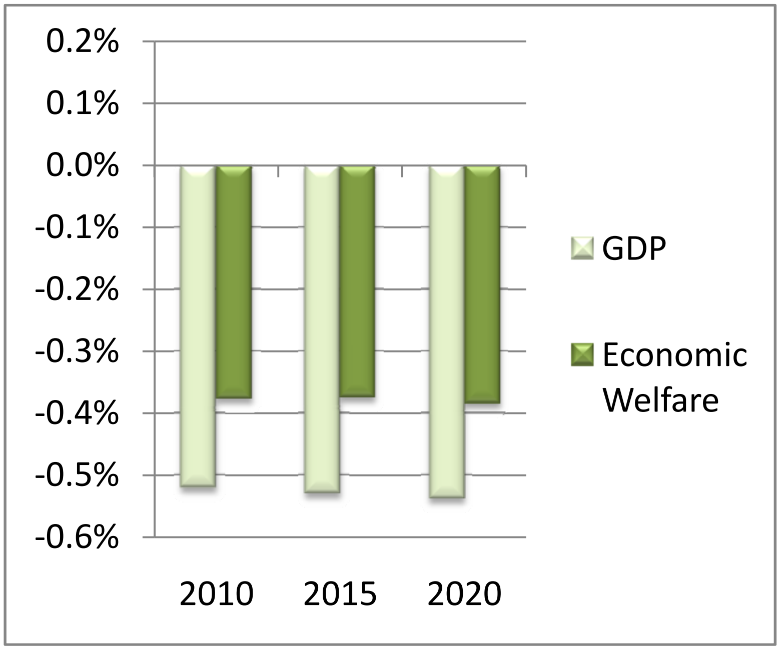

Exhibit 15. Differences in "Cost-Only" model projections of GDP and economic welfare between the *With-CAAA90* and *Without-CAAA90* scenarios.

household medical expenditures for air pollution-related health problems, and protects the quality of the environment on which economic activity and growth depend.

The current study, for the first time, attempts to capture the broader economic effect of at least some of the benefits along with all of the costs of 1990 Clean Air Act programs. This was accomplished by adjusting the macroeconomic model's inputs and configuration to reflect some of the reductions in lost work days resulting from health improvements modeled in the health effect analysis. In addition to these labor productivity improvements achieved by reducing lost work days, the "Labor Force-Adjusted" model runs were configured to include the savings in medical expenditures implied by improved health outcomes projected under the *With-CAAA90* scenario.

Exhibit 16 shows the results for the "Labor Force-Adjusted" macroeconomic modeling of the *With-CAAA90* and *Without-CAAA90* scenarios, and it is a very different set of results from the "Cost-Only" modeling results. By capturing some of the benefit-side effects, GDP eventually improves overall, and the measure of household economic welfare change produced by the macroeconomic model is positive throughout the modeled period. Compared to the 0.54% reduction in GDP for the year 2020 under the "Cost-Only" run, GDP is higher by 0.02%. More important, household economic welfare is also higher, reflecting a 2020 welfare improvement of 0.15% rather than a 0.39% reduction under the "Cost-Only" method. The 0.15% welfare improvement for households under the "Labor Force-Adjusted" method is equivalent to about $29 billion for the year 2020. This estimate of welfare improvement is much smaller than that estimated in the main benefit-cost calculations because it excludes almost all of the value of mortality risk reduction, most of which cannot yet be incorporated in the type of economy-wide model used here.

As noted above, the measure of economic welfare provided by the economy-wide model is limited. It captures only the value to households of improvements in household financial circumstances. It does not capture many of the other significant improvements to well-being measured by the direct benefits analysis, such as the value of improved longevity to people both inside and outside the formal workplace

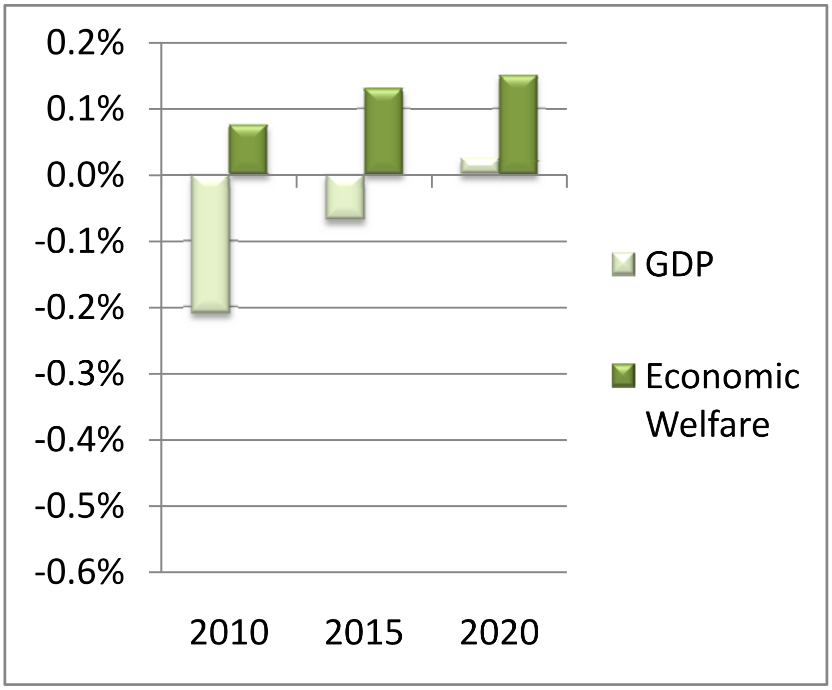

Exhibit 16. Differences in "Labor Force-Adjusted" model projections of GDP and economic welfare between the *With-CAAA90* and *Without-CAAA90* scenarios.

economy, or the value of avoiding the pain and suffering caused by air pollution-related disease. Nevertheless, the finding that both direct net benefits and measures of household financial well-being are improved by 1990 Clean Air Act Amendment programs supports an interpretation that the 1990 Act improved the economy as well as public health and environmental quality. This finding contradicts the longstanding belief of some stakeholders that air pollution control programs are always detrimental to the economy even if they improve public health and the environment.

Important Uncertainties and Limitations

Benefit-cost studies of environmental programs are often highly complex, requiring acceptance of significant uncertainties in the underlying scientific and economic information needed to estimate and value effects. In addition, environmental benefit-cost studies are significantly influenced by external factors and conditions, such as rates of technology change, shifts in rates or patterns of overall economic growth, and –in the case of air pollution studies—meteorological patterns and fluctuations over time.

To address these uncertainties in underlying scientific information and important external influences, analysts often evaluate such uncertainties by analyzing multiple scenarios to gauge the importance of both variability in conditions and uncertainty in the estimates of effects. The current study includes a range of in-depth uncertainty analyses which are described in the full report and supporting technical documents on uncertainty analysis.

For the purposes of this summary report, it is important to acknowledge the critical uncertainties and limitations in the study's data, methods, and resulting model outputs and emphasize that the results presented herein provide just one snapshot of the potential differences between conditions with and without 1990 Clean Air Act programs. Depending on the particular uncertainty or study limitation in question, the results of this study could change significantly if alternative data, methods, or assumptions are adopted.

Key Uncertainties

Most benefit-cost analyses of environmental programs, including the present study, must confront three categories of uncertain effect estimates: effects which exist but are not seen because of limited scientific information, effects which are known to scientists but which cannot be expressed in quantitative physical and/or economic value terms, and effects which can be quantified and monetized but not with certainty.

Some researchers, analysts, and stakeholders emphasize the importance of the first category of unknown effects, raising concerns about environmental benefit-cost studies which focus only on known effects. Such analyses may lead to systematic biases in evaluation of public policy, which some in turn have suggested could be addressed by considering the need for precaution in the face of unknown and/or potentially catastrophic consequences when reviewing the results of environmental benefit-cost analyses. While important, evaluation of the implications for policy of this first category of uncertain effects and strategies for ameliorating the consequences of these uncertainties is beyond the scope of this study.

This study does, however, address the second and third categories of uncertain effects. In implementing the study, it became clear that there was a large number of known effects which could not be carried all the way through the analytical sequence from effect identification to full economic evaluation. Potentially significant effects which are addressed in very limited quantitative terms, if at all, include most hazardous air pollutant effects and virtually all effects of Clean Air Act programs on ecosystems, including ecosystems services which improve human welfare and quality of life. A variety of known or suspected human health effects associated with particulate matter, ozone, or other Clean Air Act criteria pollutants were also excluded from this study's quantitative results. Some of the omitted effects considered most significant by the Study Team are listed in Exhibit 17.

Unquantified Effects
Health Effects
Cancer
Stroke & cardiovascular disease
Low birth weight
Subchronic bronchitis
Pulmonary function
Premature aging of the lungs
Inflammation of the lung
Acute respiratory cell damage
Increased respiratory infection
Behavioral & developmental effects
All health effects of hazardous air pollutants
Welfare and Ecological Effects
Recreational visibility outside California , SW States, SW States
Residential visibility outside major metropolitan areas
Agricultural effects from pollutants other than ozone
Damage to most pollution-sensitive materials
Most ecological effects

Exhibit 17. Sample of potentially significant effects which could not be effectively quantified in the present study.

Finally, there are known effects which can be valued in economic terms but the estimates presented herein could differ from their "true" values due to uncertainties in underlying studies, input data, the models used to analyze those data, or the assumptions made in the absence of data. The issues associated with uncertainty in the effects estimates included in this study are explored in detail in the full report and in greater depth in a separate technical report documenting the study's extensive uncertainty analysis. The particular uncertainties which the Study Team judged might most influence the bottom line estimate of net quantified benefits are listed in Exhibit 18.

Among the potentially major uncertainties identified in the detailed uncertainty analysis, the most important uncertainties are those which influence the following:

1. Particulate matter premature mortality
2. Ozone premature mortality
3. Economic value assigned to reductions in premature mortality risk

As mentioned briefly in the preceding section on comparison of benefits and costs, the third factor strongly influences this study's results but is uncertain. One metric often used to describe small changes in risk and their associated economic value is called the "value of a statistical life", or VSL for short. The VSL is derived by estimating the amounts people are willing to pay to gain small reductions in mortality risk, then calculating the value which is equivalent to avoiding a full instance of premature mortality (i.e., one full "statistical life"). The present study applies a range of estimates for VSL, represented by a central value of about $7.4 million (in year 2006 value dollars). As described earlier, the method is consistent with prior studies in this series and with prevailing EPA economic guidelines. Estimates for the VSL, however, may be significantly influenced by factors such as age and health status. Other factors may also influence estimates of the VSL, including the nature of the mortality risk being valued; for example whether the risk in question is voluntarily accepted through a personal decision to engage in some hazardous but rewarding activity or involuntarily imposed by external sources of air pollution.

AREA	UNCERTAINTY	EFFECT OF RESOLUTION
Emissions	Uncertainty about estimates of emissions changes under Without-CAAA90 scenario	Unknown
Emissions	Uncertainty about economic growth factors	Unknown
Emissions	Uncertainty about final form and compliance with CAMR and CAIR	Unknown
Cost	Some costs of compliance with NAAQS not captured	Lower Net Benefits
Health	Uncertainty regarding degree PM causes mortality	Lower Net Benefits
Health	Uncertainty regarding degree ozone causes mortality	Lower Net Benefits
Health	Uncertainty about effects socioeconomic status may have on PM mortality	Unknown
Health	Uncertainty regarding classification of PM exposures [need better description]	Higher Net Benefits
Health	Short-term mortality effects of PM were not captured beyond incidences captured by long-term studies	Higher Net Benefits
Health	Uncertainty about rate of reduction in PM mortality once exposure is reduced (aka "cessation lag")	Unknown
Valuation	Value of premature mortalities avoided is based on a Weibull distribution of 26 relatively old studies	Unknown
Valuation	Uncertainty regarding transfer of mortality risk reduction values from one population or set of circumstances to others (aka "benefits transfer")	Unknown
Valuation	Uncertainty about adjustments to value people assigned to effects based on their income	Unknown
Ecological	Incomplete coverage of effects	Higher Net Benefits
Ecological	Incomplete coverage of long-term bioaccumulative and persistent effects	Higher Net Benefits

Exhibit 18. Potentially major uncertainties and the estimated effect elimination of each uncertainty may have on this study's results.

The uncertainties surrounding the VSL used to translate the small but widespread reductions in risk of premature mortality under the *With-CAAA90* scenario are important to consider when interpreting the results of this study. For example, if a different central estimate for the VSL were adopted, the year 2020 Primary Central estimate of $1.8 trillion in direct benefits from avoided premature mortality would be affected proportionately.

Key Limitations

Practical constraints on available time and resources often require compromises in study design and implementation which limit the scope of the insights which can be obtained from an analysis. Furthermore, benefit-cost studies often involve comparison of alternative potential states of the world for which information is limited or even nonexistent. Four particularly important analytical limitations are manifest in this study.

One representation of potential states of the world

The study configures and analyzes one particular current and future pathway of Clean Air Act implementation and contrasts it with a counterfactual baseline which assumes Federal, State, and local standards were not updated after passage of the last amendments to the Clean Air Act in November 1990. While useful to illustrate the overall incremental benefits and costs of the 1990 Amendments and their related programs and policies, neither scenario is intended to represent a definitive historical account or projection of potential past or future states of the economy, public health, and the environment. Nevertheless, a reasonable representation of the potential contrasts between these two representations of the world with and without 1990 Clean Air Act Amendment programs is useful. This is why the study focuses on the differences between the two main scenarios, and does not focus on absolute conditions since the simplified representations of the scenarios would not be expected to match real world conditions which are influenced by year to year fluctuations in key factors, such as meteorological conditions and business cycles.

Fixed effects

Another important, related limitation arises due to the complexity and scope of the analysis, which are so great that certain potentially important factors had to be kept fixed between the scenarios in order to make the analysis feasible. In addition, certain factors were held fixed so the study would remain focused on the particular influence of 1990 Clean Air Act programs on the environment and the economy. For example, the study did not assume any differences between the *With-CAAA90* and *Without-CAAA90* scenarios in terms of total electricity demand or the distribution of economic activity and population, though some interactions between clean air policies and these conditions can be expected. Nevertheless, the study does provide an overall perspective on the magnitude and broad distribution of the effects of the 1990 Clean Air Act on the U.S. economy, population, and environment.

Aggregated results

To support effective evaluation and design of air pollution control programs, it is useful to analyze the relative value of controlling different pollutants, and also to compare the cost-effectiveness of controls applied to different sources. Furthermore, pollution reductions in one location may yield a greater return on investment than reductions achieved in another location. For this reason, it would have been desirable to configure this study to provide benefit-cost results disaggregated by pollutant, source category, major program area, and/or location. However, while costs can be reported by source category or major program area, benefits are estimated by pollutant. Even reporting benefits by individual pollutant is complicated given interactions among pollutants which influence overall changes in air quality and in health or environmental outcomes. As a result, the only way to provide disaggregated benefit and cost results by individual pollutant, by location, or by source is to configure and run the entire benefit-cost modeling system in a manner which isolates a given pollutant or location or program. This level of resource investment was beyond reach for the present study. Therefore, this study does not support comparisons of net benefit or cost-effectiveness across pollutants, economic sectors or geographic areas.

Interactions with climate change programs and outcomes

This study is unique because it captures the significant interactions among various criteria pollutant control programs, such as the combined effects of reducing different fine particle precursors across a range of stationary and mobile sources. However, even this study's broad scope is insufficient to capture interactions between pollutant reductions achieved by current Clean Air Act programs and the potential costs and benefits of programs to address climate change. Because Clean Air Act criteria pollutants, hazardous air pollutants, and greenhouse gases are all associated with the same major emissions sources, such as utility powerplants, an ideal evaluation of Clean Air Act program benefits and costs would include consideration of the interactions among programs to address all three categories of air pollution and the outcomes achieved by such programs.

Conclusions

The objectives of this study included estimation of the incremental direct benefits and costs of the 1990 Clean Air Act Amendments, evaluation of economy-wide effects, assessment of a broad range of effects with potential significance for stakeholders and researchers, and consideration of the implications of study limitations and uncertainties for research and the design of future studies. Considering these objectives and the results obtained, EPA reaches the following conclusions.

1. The direct benefits of the 1990 Clean Air Act Amendments and associated programs significantly exceed the direct public and private costs of these programs, even when counting only those effects which could be evaluated in economic terms.

2. Macroeconomic modeling of the scenarios evaluated in this study indicates the broader economy is improved overall by the 1990 Clean Air Act and related programs. Cleaner air is projected to result in significant improvements in worker health and productivity and reductions in medical costs. Other potentially significant economic benefits, such as improved longevity, could not be captured; however, the reductions in work loss days and savings on medical costs alone eventually more than offset the costs of investing in air pollution controls, as demonstrated by modeling results which show positive net effects of the 1990 Clean Air Act on GDP growth and the economic welfare of American households.

3. The significant uncertainties and limitations which persist for benefit-cost studies of air pollution control programs imply the need for ongoing investments in research to improve data and methods. In particular, research is needed to improve the range of effects which can be quantified and evaluated in economic terms and to reduce important uncertainties in the estimates of currently quantified effects.

4. Efforts to design and implement the current study, and the results obtained, led the Study Team to identify several potential improvements to future analytical efforts. As described in the next section, future evaluation of Clean Air Act programs might be improved through scenarios analysis or an alternative analytical framework capable of evaluating criteria pollutant, hazardous air pollutant, and climate change pollutants in an integrated manner.

Looking Ahead

Beyond the intrinsic value of the present study with respect to its defined goals and objectives, there are at least two additional potential uses for this study. First, the methods or results of the study may contribute directly to other studies. Second, the lessons learned from efforts made pursuant to this study may provide insights which improve future research and the design of future studies.

Additional direct uses for the present study

Energy externalities

The methods and results of the First Prospective Study were used by the National Academy of Sciences to support their analysis of energy externalities (see National Research Council, *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*, June 2010). The current, Second Prospective Study could provide significantly improved information in support of future efforts to estimate the criteria pollutant-related externalities associated with energy production and use.

Data, methods, and modeling tools

The Advisory Council for Clean Air Compliance Analysis (Council) and its technical subcommittees provided effective and rigorous evaluation of the data and methods used in the present study. EPA and other federal agencies, States and local agencies, and other researchers may find the methods developed and/or evaluated herein to be useful for their work. For example, since the Second Prospective Study adopts a relatively consistent analytical framework for evaluating a broad range of controls across multiple emissions sectors, its results could be adapted to provide useful metrics such as relative "dollar per ton" estimates. Such "rule of thumb" valuation metrics could provide useful benchmarks for judging the expected value of local investments in particular control measures.

Improving future studies

Redesigning analytical frameworks

Some of the limitations in the information this and other current studies provide to policymakers and the public can be addressed by redesigning the scope and frameworks for analysis to better capture important interactions among pollution control programs. It may be especially useful to explore building an analytical framework which evaluates criteria pollutant control programs in conjunction with programs to address climate change. An approach which focuses on analyzing broad scenarios, rather than small incremental differences in individual programs, may provide more useful insights into the ways such programs interact, capturing important effects of one program which influence the costs or effectiveness of other programs. For example, under a scenario involving unchecked greenhouse gas emissions, it is reasonable to anticipate an atmosphere prone to more and worse extreme temperature days. An increase in extreme temperature days may lead to more Code Red air quality alerts for ozone, which may lead to a reduction in outdoor activity, which may lead to greater use of air conditioning, which may lead to higher fine particle emissions from coal-fired powerplants due to higher demand for electricity to run those air conditioners. A scenarios analysis approach would allow analysts to capture important consequences of one program when evaluating policy options for another control program. A scenarios analysis approach might also allow more realistic treatment of other external trends and conditions which influence a program's cost and prospects for success. Examples of factors which could be treated in a more consistent manner under a scenarios analysis approach include patterns of economic growth, rates of technological development, patterns and intensity of fuel use, changes in atmospheric conditions, and population behavioral responses to clean air programs.

Value of Information analysis

Formal Value of Information analysis has rarely been applied in evaluations of air pollution control programs. Value of information principles are sometimes followed informally in the design and implementation of studies, as they were for the present study. However, more formal exercises aimed at assessing the policy and analytical implications of uncertainties in key variables could help guide priority-setting for research, analytical design, and efforts to improve data and methods.

Ex ante versus *ex post* evaluations of data and modeling tools

Data and modeling tools could also be improved by more extensive evaluation of the validity of existing data and the performance of current models. Though not all data and modeling tools can be evaluated in this manner, formal data and model validation exercises based on comparisons of *ex ante* projections and *ex post* outcomes (e.g., comparing projections from current air quality models against air quality monitoring data) could improve the accuracy and reliability of future air pollution program benefit-cost studies.

Improved sharing of data and methods development

Sharing of data among researchers usually leads to significant improvements in the quality and usefulness of information. Formal collaborations among researchers to develop improved analytical methods could also significantly improve the quality of air pollution program benefit-cost analysis. For example, the Council panel which reviewed the initial analytical blueprint for the present study recommended the Agency consider organizing “Learning Laboratories” focused on addressing particularly important analytical challenges through a public-private collaborative process aimed at developing and vetting new methods and assumptions. The current Council panel proposes more extensive release to the public of underlying data for use and improvement by other researchers. Both initiatives could lead to significant improvements in air pollution program evaluations.

Beyond the existing Clean Air Act

The statutory language defining the parameters for the present study limited its scope to evaluation of the effects of the existing Clean Air Act. However, since the Clean Air Act was last amended in 1990, the science and economics of air pollution control have progressed significantly. For example, much has been learned in recent years about the role ammonia plays in formation of the secondary particles which dominate this study’s estimates of direct benefits. Future air pollution control program evaluations could be expanded to consider pollutants which may be beyond the scope of existing Clean Air Act authorities so the potential value of addressing such pollutants is clarified for policymakers and the public.

Cheaper, faster, better

Benefit-cost analysis of air pollution control programs are enormously complicated exercises, usually requiring operation of a long chain of highly complex models involving numerous, large data sets. The resource and time burdens of exercising the modeling systems used in the present study were so great that they precluded conduct of the multiple model system runs which could have provided policy-useful results disaggregated by pollutant, program element, and/or location. EPA continues to engage in and support model development efforts aimed at reducing the time and cost required to evaluate air pollution control program effects, while maintaining the high standards for scientific and economic rigor expected of EPA analysis. Achieving further gains in data quality and model speed and performance, and improving linkages between models in the analytical sequence, will require significant ongoing investment in model development. However, the results of this study demonstrate that the effects of 1990 Clean Air Act programs on public health, the environment, and the economy are so significant that improving Agency capabilities to conduct such analyses would appear to be a sound investment.

Frequently Asked Questions

Can the results of this study be added to the Retrospective study to get a full picture of the benefits and costs of clean air programs since the 1970 Act?

The Retrospective Study evaluates the benefits and costs of the 1970 Clean Air Act and its 1977 Amendments up through the year 1990. The current Second Prospective Study evaluates the incremental effect of the 1990 amendments, using a baseline which reflects continuation after 1990 of only those programs in place when the 1990 amendments were passed. The results of the two studies, therefore, are at least conceptually additive. However, any attempt to add the benefits and costs estimated by these two studies would reflect at least two significant shortcomings. First, the Retrospective Study used data and modeling tools which are significantly different from those applied in the current study. If the Retrospective Study were done again using current data and modeling tools, the resulting estimates of benefits and costs would be significantly different. The second deficiency which must be confronted when adding the results of the two studies is that neither study provides information about the post-1990 effects of 1970 and 1977 Clean Air Act programs, except to the extent they are directly superseded by 1990 Amendment requirements and programs.

What about the benefits of reductions in hazardous air pollutants achieved by Title III? Are those counted?

The costs of complying with Title III Maximum Achievable Control Technology (MACT) standards for hazardous air pollutants are included in the Primary Estimates. These MACT standards achieved reductions in volatile organic compound (VOC) emissions beyond the VOC reductions attributed to other Clean Air Act titles. Therefore, while the incremental effects of Title III programs on criteria pollutant emissions are captured, the benefits of reductions in the direct toxic effects of hazardous air pollutants across the country are not captured. Pursuant to the study's goal to assess a broad range of potentially important effects, a case study evaluating the costs and benefits of reduced exposures to benzene achieved by the 1990 Clean Air Act in the Houston area was conducted. A central purpose of the case study was to explore the specific data and model deficiencies which currently preclude effective quantification of hazardous air pollutant reduction benefits, perhaps providing insights to guide future research and development efforts. The benzene case study is available as a supporting technical document for the Second Prospective Study.

Isn't it likely other actions would have been taken at the federal, State, local or even private levels to address the problem of worsening air pollution if the 1990 Clean Air Act hadn't been enacted? So isn't the study giving too much credit to the Clean Air Act for all the air quality improvements since 1990?

The projected air quality conditions under the *Without-CAAA90* scenario are significantly worse than projected under the *With-CAAA90* case, so it does seem likely actions would have been taken through other federal programs, State/local regulations, and/or voluntary private actions to protect air quality. The extent and character of the alternative actions which might have been pursued, however, are unknown. Such measures would have also imposed costs, perhaps similar to those estimated herein and attributed to the 1990 Clean Air Act Amendments. Since it is a matter of speculation what actions may have been taken in the absence of the 1990 Amendments, the present study is designed to show the difference between a world with and without all the federal, State, and local programs associated with the 1990 Amendments. As such, this study is best interpreted as capturing the value of the full range of public and private actions taken to improve air quality to levels consistent with overarching federal law. Significant credit is due to EPA's State and local partners, and to private firms and individuals, for the significant benefits achieved by the improvements in air quality and the resulting net benefits estimated by this study.

Is it plausible that clean air programs are responsible for yielding benefits equal in value to $6,000 per person, a figure which is about 6-7% of projected mean personal income in 2020?

It is true that this study's direct benefit results imply a very substantial gain in value to people living in the United States, especially from reductions in risk of particulate matter-related premature mortality. The difference in health outcomes with and without 1990 Clean Air Act programs may be so great that the customary measures used to translate small, marginal changes in health outcomes to dollar values may misestimate the economic value of the non-marginal changes in health outcomes between the two scenarios analyzed. This issue warrants further consideration. Nevertheless, there is an important difference between the value people may assign to improved health and what it costs them to acquire it. It is not the case that Americans had to spend $6,000 per person per year for the cleaner air achieved by 1990 Clean Air Act programs. Instead, as shown by the direct cost results of this study, the costs to society of implementing these programs only reaches about $200 per capita by 2020, the study year when the incremental costs are highest. The $6,000 figure is more of a dollar-based value for the welfare improvement people enjoyed by avoiding the poor air quality conditions projected under the *Without-CAAA90* scenario, and is not an estimate of what people actually had to pay for the improvements in health, welfare, and environmental conditions achieved by 1990 Clean Air Act programs.

The Second Prospective Study results are dominated by the benefits of reducing overall exposures to fine particulate matter. But there are several different species of fine particles, including sulfates and nitrates, and there is some evidence they aren't all equally toxic. Why didn't the study evaluate the possibility that some species of fine particulates are more toxic than others?

Scientific evidence establishing the potential differential toxicity of particle species is still considered by EPA to be insufficient to support effective analysis of the potential consequences if specific species of fine particles are found to manifest different degrees of toxicity. Available epidemiological studies supporting the association between particulate matter exposure and health effects such as premature mortality are based on aggregate measures of particulate matter exposure. Assuming one particular species is more toxic requires adjustments to the known or presumed toxicity of all other particle species, including potentially critical interaction effects among them. Absent adjustments to maintain coherence, the set of differentiated, species-specific concentration-response functions developed for analytical purposes may be inconsistent with the underlying health studies. While notional species-specific risk coefficients might theoretically be constructed, EPA believes that unfounded and inconsistent species-specific risk functions would be highly uncertain and could be biased, leading to analytical results which may be significantly more misleading than informative. There is ongoing research on the issue of potential differential toxicity of fine particles and EPA looks forward to improvements in the scientific information available to address this question.

The study uses a model of the overall economy to estimate changes due to the 1990 Clean Air Act Amendments, including GDP and a measure of "economic welfare." Does this measure of economic welfare capture everything that affects people's well-being?

The formal, measured economy captures many aspects of the welfare of households, such as wages earned and the cost of goods and services. However economic models do not capture everything which affects people's welfare. For example, economic models do not directly capture the full costs of adverse health effects from air pollution. They may capture what people spend for preventive measures or medical costs, but they don't effectively capture the value people assign to avoiding the pain and suffering, inconvenience, or many other costs of being afflicted. In this sense economic welfare as measured in a model of the overall economy provides only a limited measure of the changes which affect quality of life. For this reason, the principal focus of the present study is to estimate the direct benefits of air quality improvements using more complete, "willingness to pay" measures of economic value and comparing those direct benefits to the direct costs of regulatory compliance. Both measures of welfare change, however, provide potentially useful insights about the economic and welfare consequences of Clean Air Act programs.

Why doesn't this study include the costs and benefits of climate change programs?

The 1990 statutory language establishing this series of Clean Air Act benefit-cost studies did not include climate change program evaluation within its scope. However, EPA has conducted numerous studies assessing the environmental and economic effects of proposed climate change programs. In the future, EPA expects to conduct and/or encourage studies which more effectively integrate evaluations of climate change policy options with evaluations of ongoing and future Clean Air Act programs.

Does this study predict what will happen in particular locations, especially whether a given county or State or air quality management district will or won't attain federal air quality standards in the future?

This study focuses on analyzing differences in air quality between one particular, assumed pathway for implementation of the 1990 Clean Air Act versus a hypothetical, counterfactual state of the world without the 1990 Act. As such, though the study applies several models which have high levels of spatial detail and are used for attainment demonstrations, the study focuses on estimating potential differences in air quality between two constructed scenarios over a period of decades and across the entire 48 States. It therefore does not provide the kind of highly localized analyses of location-specific meteorological data, control measures, and consecutive year air quality change which are used to determine attainment with air quality standards. Nevertheless, the study does provide insights on the overall magnitude of 1990 Clean Air Act compliance costs and the substantial benefits achieved by the measures taken.

For further information

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Electronic copies of the full integrated report and all publicly available supporting technical documents are available online at: *http://www.epa.gov/oar/sect812/prospective2.html*

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