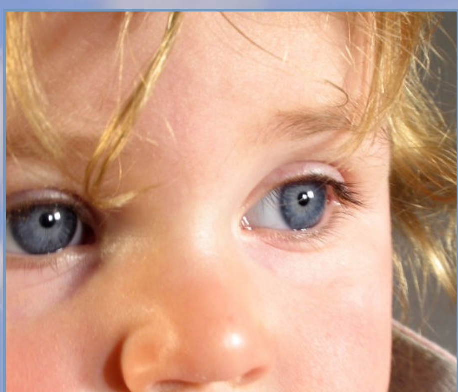
The Benefits and Costs of the Clean Air Act from 1990 to 2020



U.S. Environmental Protection Agency
Office of Air and Radiation
March 2011

SUMMARY REPORT

Acknowledgements

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 and this summary report were reviewed by the EPA Science Advisory Board's Advisory Council on Clean Air Compliance Analysis (hereafter the Council) and its three technical subcommittees. The individual detailed reports that focus on each of the key analytical components of the overall study were also reviewed by the Council and/or one or more relevant subcommittees.

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.

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Study Review Panels

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

For further information

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 reports documenting particular analytical tasks, such as estimation of compliance cost and projection of air quality changes. Data presented in this summary report are documented in the full integrated report and/or the supporting technical analyses.

Electronic copies of this summary report, the full integrated report, and all publicly available supporting technical documents can be downloaded at: *http://www.epa.gov/oar/sect812/prospective2.html*

Paper copies of this summary report can be obtained by submitting a request indicating the number of copies required to: *CAAA.Benefit-Cost-Study@epa.gov*

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Summary of Findings and Recommendations

Findings

This study evaluates the benefits and costs of programs implemented pursuant to the 1990 Clean Air Act Amendments, relative to a hypothetical baseline which assumes control programs established under the 1970 Clean Air Act and 1977 Amendments stayed fixed at their 1990 levels of scope and stringency. The study applies the framework and principles of benefit-cost analysis to estimate significant beneficial and costly effects of these programs, express these effects where feasible and appropriate in dollar value terms to facilitate comparison of disparate effects, and then calculate the overall net economic benefits (benefits minus costs) of the changes in Clean Air Act-related programs resulting from the 1990 Amendments.

- Based on the scenarios analyzed in this study, ***the costs of public and private efforts to meet 1990 Clean Air Act Amendment requirements*** rise throughout the 1990 to 2020 period of the study, and ***are expected to reach an annual value of about $65 billion by 2020.***[1]

- ***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 cost of efforts to comply with the requirements of the 1990 Clean Air Act Amendments.

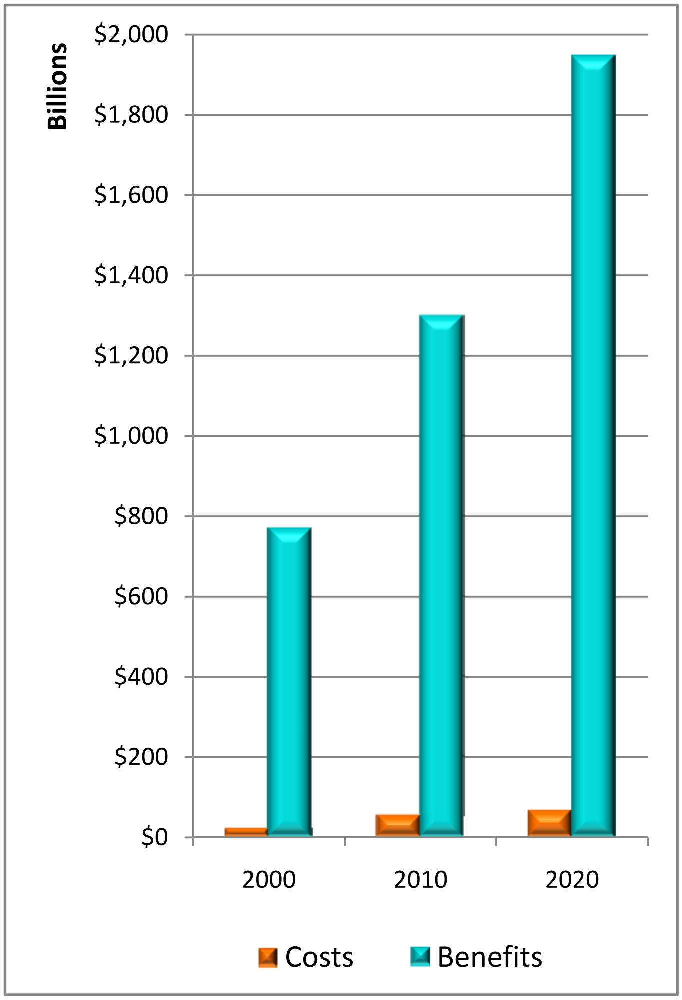

Exhibit 1. Primary Central Estimates of direct benefits and direct costs for the 2000, 2010, and 2020 study target years. (In billions of 2006 dollars). The graph shows the extent to which benefits exceed costs throughout the study period.

[1] Because of inflation, the value of a US dollar varies from year to year. In this study, dollars are defined according to the value they held in the year 2006.

- ***The extent to which estimated benefits exceed estimated costs*** and an in-depth analysis of uncertainties ***indicate that it is extremely unlikely the costs of 1990 Clean Air Act Amendment programs would exceed their benefits under any reasonable combination of alternative assumptions or methods identified during this study***. Even if one were to adopt the extreme assumption that air pollution has no effect on premature mortality –or that avoiding such effects has no value—the benefits of reduced non-fatal health effects and visibility improvements alone are more than twice the total cost of compliance with 1990 Clean Air Act Amendment requirements.

- Economy-wide modeling was also conducted to estimate the effect of the 1990 Amendments on overall U.S. economic growth and the economic welfare of American households. ***When some of the beneficial economic effects of clean air programs were incorporated along with the costs of these programs, economy-wide modeling projected net overall improvements in economic growth and welfare.*** These improvements are projected to occur because cleaner air leads to better health and productivity for American workers as well as savings on medical expenses for air pollution-related health problems. The beneficial economic effects of these two improvements more than offset the costly effects across the economy of expenditures for pollution control.

- ***The most significant known human health effects from exposure to air pollution are associated with exposures to fine particles[2] and ground-level ozone pollution***. Many of these effects could be quantified for this study; but other health effects of fine particles and ozone, health effects associated with other air pollutants, and most air pollution-related environmental effects could be quantified only partially, if at all. Future improvements in the scientific and economic information needed to quantify these effects would be expected to further increase the estimated benefits of clean air programs.

[2] Particle pollution, also known as "particulate matter" or PM, is a term used to describe a broad class of extremely small solid particles and liquid droplets suspended in the air. Particle pollution can include one or more different chemical components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles. The size of particles has been linked to their potential for causing health problems since it is easier for smaller particles to bypass protective mechanisms in the nose and throat and enter deeply into the lungs. The number which sometimes follows the term PM refers to the aerodynamic diameter of particles expressed in units of microns (millionths of a meter); so PM2.5, for example, refers to a mixture of aerosol particles which are less than or equal to 2.5 microns. EPA classifies particle pollution into two main categories: (1) "inhalable coarse particles" such as those often seen near roadways and dusty industrial activities, which are larger than 2.5 microns but smaller than 10 microns, and (2) "fine particles" such as those found in smoke and haze, which are 2.5 microns and smaller. The terms PM2.5 and "fine particles" therefore refer to the same fraction of particle pollution.

Recommendations

The findings of this study have potentially significant implications for policy, programs, and research related to air pollution in the U.S. The recommendations presented below focus on research needs and the expansion and refinement of future studies.

- Clean Air Act programs address a wide variety of air pollutants beyond the fine particle and ozone pollution which emerged as the primary focus of this study's quantitative results. The data and modeling tools needed to estimate the health and environmental consequences of these other pollutants, however, are limited. ***There is an ongoing need for investment in research to improve the coverage of potentially important effects in benefit-cost studies of air pollution control programs.*** Additional research is also needed to reduce uncertainties in the estimates of effects already incorporated in benefit-cost studies, especially relatively significant effects such as those associated with fine particle- and ozone-related premature mortality and the economic value of avoiding those outcomes.

- Programs to reduce key Clean Air Act pollutants through national ambient concentration standards such as those for fine particles and ozone, programs to address air pollutants with more localized affects such as toxic compounds and heavy metals, and programs and policies which reduce emissions of greenhouse gases may impose various requirements on a given source of emissions. ***Future air pollution program assessments would be more useful to policymakers and the public if they were designed to provide insights on the combined effects of programs to address these different categories of air pollution.***

- Typical macroeconomic modeling tools and practices tend to focus on assessment of effects across the economy of compliance expenditures while ignoring the economy-wide benefits of cleaner air. ***Consideration should be given to improving macroeconomic modeling of major environmental programs so their benefits as well as their costs are reflected in projections of how these programs 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 was published in 1997. This first study estimated the benefits and costs through 1990 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 Amendments,[3] 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 further out into the future by evaluating the costs and benefits of 1990 Clean Air Act Amendment programs through the year 2020.

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. Clean Air Act Section 312 statutory language (abridged) as amended by Section 812 of the 1990 Amendments. The text of the law defines Congress' direction to EPA regarding the scope and review of these studies.

[3] The Clean Air Act is comprised of a number of statutory titles. Title I requires attainment of national air quality standards for designated pollutants such as ozone, Title II focuses on mobile source control programs, Title III addresses hazardous air pollutants, Title IV establishes programs to address acid deposition and related effects, Title V establishes permitting requirements, and Title VI focuses on protection of the stratospheric ozone layer.

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 EPA Regulatory Impact Analyses.

The effects of the 1990 Clean Air Act Amendments 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.

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 would 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 supplementary objectives. Consistent with the central objectives defined for the two preceding studies, the current study was designed to estimate the direct[4] costs and direct benefits of the Clean Air Act as a whole, 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.

[4] In this study, "direct" costs or benefits refer to first-order economic effects of pollution control programs. For example, the expenditure of funds to purchase, install, and operate pollution control equipment is considered a direct cost of a pollution control program. Similarly, the reduction in risk of a pollution-related health effect is a direct benefit of the reduction in emissions achieved by the use of that equipment. Indirect effects are those which emerge as consequences of the direct effect, such as the higher cost of producing steel if the direct cost to an electric utility of installing pollution control equipment leads to an increase in electricity prices paid by a steel plant. An example of an indirect benefit is the improvement in worker productivity achieved when the direct benefit of avoiding pollution-related illness helps workers avoid sick days. The present study focuses on evaluation of direct benefits and costs but also, to a limited extent, assesses indirect effects through economy-wide modeling.

EPA also sought, as a third objective, 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 any 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 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 1990 Amendments were not passed.

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-CAAA* case for short, and it represents a world of lower emissions but higher costs following enactment of the 1990 Clean Air Act Amendments. The *With-CAAA* case is represented by the lower line in Exhibit 3, which depicts a not-to-scale schematic illustrating the scenarios analyzed.

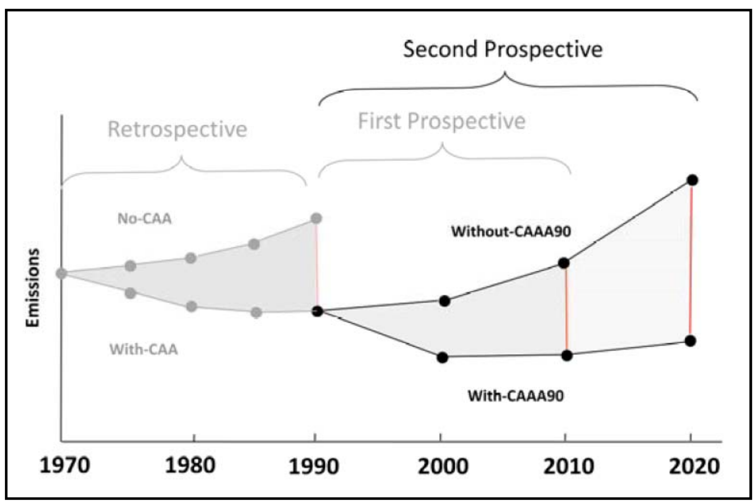

Exhibit 3. Second Prospective Study scenarios conceptual schematic. This exhibit is a schematic depiction of the scenarios to illustrate their timing and conceptual foundations.   The differences in emissions between studies and between years are not to scale and should not be viewed as a comparison of emission reductions achieved between studies or between years.

The second, contrasting scenario reflects a hypothetical world which assumes federal Clean Air Act and related programs were frozen as of November 1990, the month the Amendments were signed into law. Therefore, 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-CAAA* case. The hypothetical *Without-CAAA* 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-CAAA* and *Without-CAAA* 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-CAAA* scenario. Several important programs, however, have been initiated or revised since the analytical scenarios were locked for the study in late 2005. For example, the *With-CAAA* 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 a different rule designed to address the problem of long-range atmospheric transport of air pollution. Information about the estimated benefits and costs of recent rules is available in the relevant EPA Regulatory Impact Analyses.

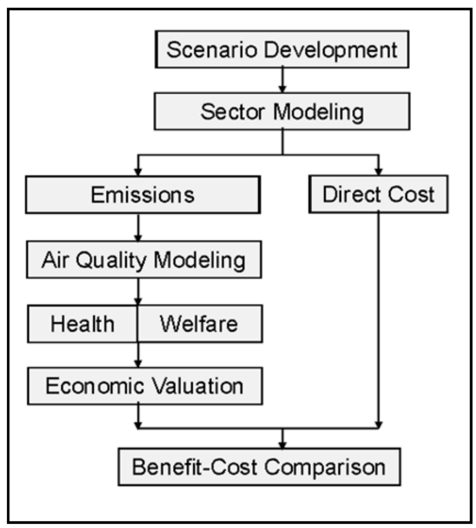

Exhibit 4. Analytical sequence of the Second Prospective Study. This flowchart shows the order of the major analytical steps followed to conduct the study.

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 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, which included substantial expertise in economics.

Primary Results

Direct Cost

Compared to the baseline scenario without the 1990 Clean Air Act Amendments and related programs, the *With-CAAA* 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:

1. **Electricity generating units** (e.g., coal-fired power plants)
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)

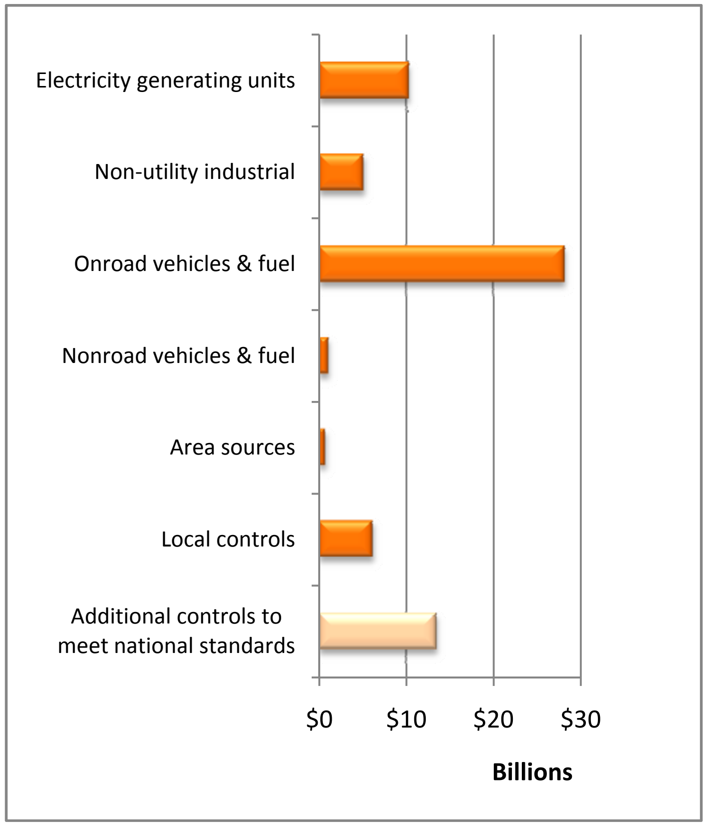

Exhibit 5. Year 2020 direct cost of compliance by source category. (In billions of year 2006 value dollars). The first five darker orange bars show how compliance costs compare for the five major categories of emissions source. Additional controls applied to these five source categories at the local level for the purposes of meeting air quality standards are shown by the sixth darker orange bar. The seventh, lighter orange bar also reflects additional local controls but these are shown separately because their costs are significantly more uncertain.

The costs incurred to reduce emissions from these sources under the 1990 Clean Air Act Amendments are estimated to rise steadily throughout the 1990 to 2020 study period. By 2020, the study target year when differences between the *With-CAAA* and *Without-CAAA* 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, 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 fine particles and ozone.

Implementation of federal and regional control programs to meet the national fine particle 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 and attain the national standards. 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, reaching the 8-hour National Ambient Air Quality Standard (NAAQS) for ozone in some locations appears to be a significant challenge. Some of these locations are assumed under the *With-CAAA* scenario to apply all controls identified as technologically feasible and cost-effective for their location yet still show modeled ozone concentrations higher than the 8-hour national standard. The *With-CAAA* scenario therefore assumes additional emissions reductions are achieved using "unidentified controls" of unknown cost and/or technological availability and applicability. Since the particular control strategies for each of these locations cannot currently be identified, their costs are highly uncertain. The *With-CAAA* scenario assumes that the additional emissions reductions achieved by unidentified controls will cost $15,000 per ton. The $15,000 per ton assumed value 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, although there is some evidence that local areas would be reluctant to implement measures that cost more than $15,000 per ton. The total incremental cost of these additional local controls using unidentified technologies is estimated to be $13 billion. Given the relatively high level of uncertainty in this component of Clean Air Act program compliance costs, it is reported as a subtotal separate from the identified control measures subtotal of $52 billion.

Emissions Reductions

The controls applied across the major categories of emissions sources under the *With-CAAA* scenario achieve substantial reductions in emissions contributing to ambient concentrations of fine particles, ozone, and other air pollutants. As shown in Exhibit 5, the total costs of control from some sectors – such as electricity generating units and onroad vehicles and fuels—were high relative to other source categories, but these sources also achieved the greatest reductions in emissions. For example, onroad vehicles and fuel represent 46% of total control costs in 2020 but they also contribute 41% of the year 2020 reduction in total NO_X emissions. The full range of emissions reductions estimated under the *With-CAAA* 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 fine particles and ozone are highlighted in Exhibit 6.

In addition to directly-emitted fine particles,[5] three other pollutants designated for control under the Clean Air Act contribute to increases in ambient concentrations of fine particles through secondary formation and transport in the atmosphere.[6] For example, gaseous sulfur dioxide can be transformed in the atmosphere to particulate sulfates. Volatile organic compounds (VOCs) and nitrogen oxides are also key pollutants contributing to the formation of ground-level ozone.

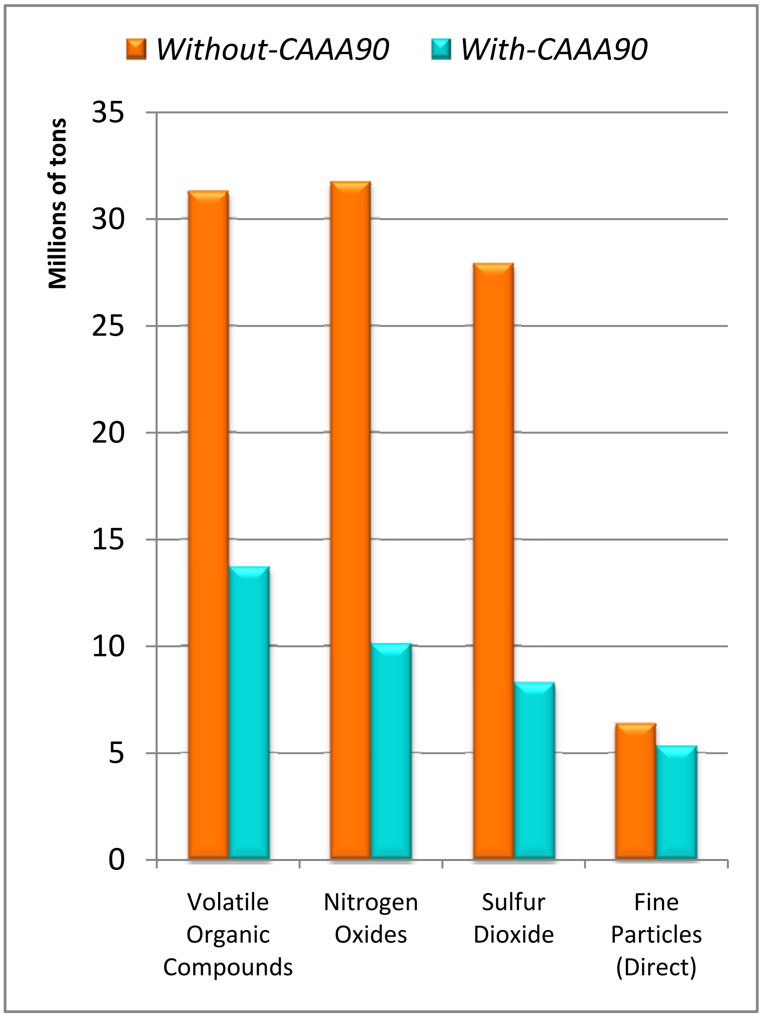

Exhibit 6. Year 2020 key pollutant emissions under the *With-CAAA* and *Without-CAAA* scenarios. (In millions of short tons). The difference in height between the orange and blue bars for each pollutant shows the estimated reduction in that pollutant achieved by 1990 Clean Air Act Amendment programs.

The estimated *With-CAAA* scenario emissions reductions depicted in Exhibit 6 are large because they reflect both absolute reductions relative to 1990 base year conditions and avoided increases in emissions which result under the *Without-CAAA* 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 result if Clean Air Act standards stay fixed while population and economic activity grow.

[5] Fine particle pollution already in a solid or liquid aerosol state at the point of emission from a tailpipe or construction site is commonly referred to as "directly emitted fine particles," or sometimes "primary particles." In contrast, fine particles which form in the atmosphere later from gaseous precursors, such as sulfur dioxide, are referred to as "secondary fine particles."

[6] In recent years the importance of ammonia in secondary formation of fine particle air pollution has become clearer. However, unlike the other pollutants shown in Exhibit 6, ammonia is not currently a designated air pollutant under the Clean Air Act, and there are no explicitly assumed differences in control requirements for ammonia between the *With-CAAA* and *Without-CAAA* scenarios.

Most of the reduction in volatile organic compounds is achieved by controls on evaporative emissions from area sources such as household solvents, controls on vehicle and nonroad engine tailpipe and evaporative emissions, and controls on non-utility industrial sources.

For nitrogen oxide emissions, all five major source categories achieve emissions reductions under the *With-CAAA* 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 particles also reduce nitrogen oxides emissions.

Electricity generating units such as coal-fired power plants are the source category which achieves the most significant reductions in sulfur dioxide emissions, accounting for about 75 percent of the total reduction projected in 2020. Cap-and-trade programs, the Clean Air Interstate Rule, and other control programs implemented pursuant to the national fine particle standards account for most of the estimated difference in sulfur dioxide emissions between the *With-CAAA* and *Without-CAAA* 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 toward meeting the requirements of the national ambient air quality standards for fine particles.

Air Quality Improvements

The substantial reductions in emissions which contribute to ambient concentrations of ozone and fine particles lead to significant differences in modeled air quality conditions under the *With-CAAA* and *Without-CAAA* scenarios. Air quality modeling results for all pollutants and all target years analyzed in this study are available in the full report, though the estimated change in fine particle concentrations is highlighted here because reductions in exposure to this pollutant are responsible for the vast majority of benefits which could be evaluated in economic terms for this study.

Exhibit 7 shows that reductions in fine particle concentrations by 2020 are large and widespread, as demonstrated by the pervasive blue colors indicating improvement in air quality. The most significant reductions occur in California and the Eastern U.S., especially the Ohio Valley region, primarily due to sulfur reductions from electric utilities and industrial facilities combined with mobile source reductions concentrated around heavily-populated metropolitan areas. Because these areas had relatively high fine particle concentrations in the 1990 base year, the modeling results imply that 1990 Clean Air Act Amendment programs were effective in targeting high emissions sources in and around locations 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-CAAA* scenario due to localized effects related to electrical generating unit dispatch or fuel choice. These localized disbenefits, shown by the isolated spots of orange color in Exhibit 7, are negligible

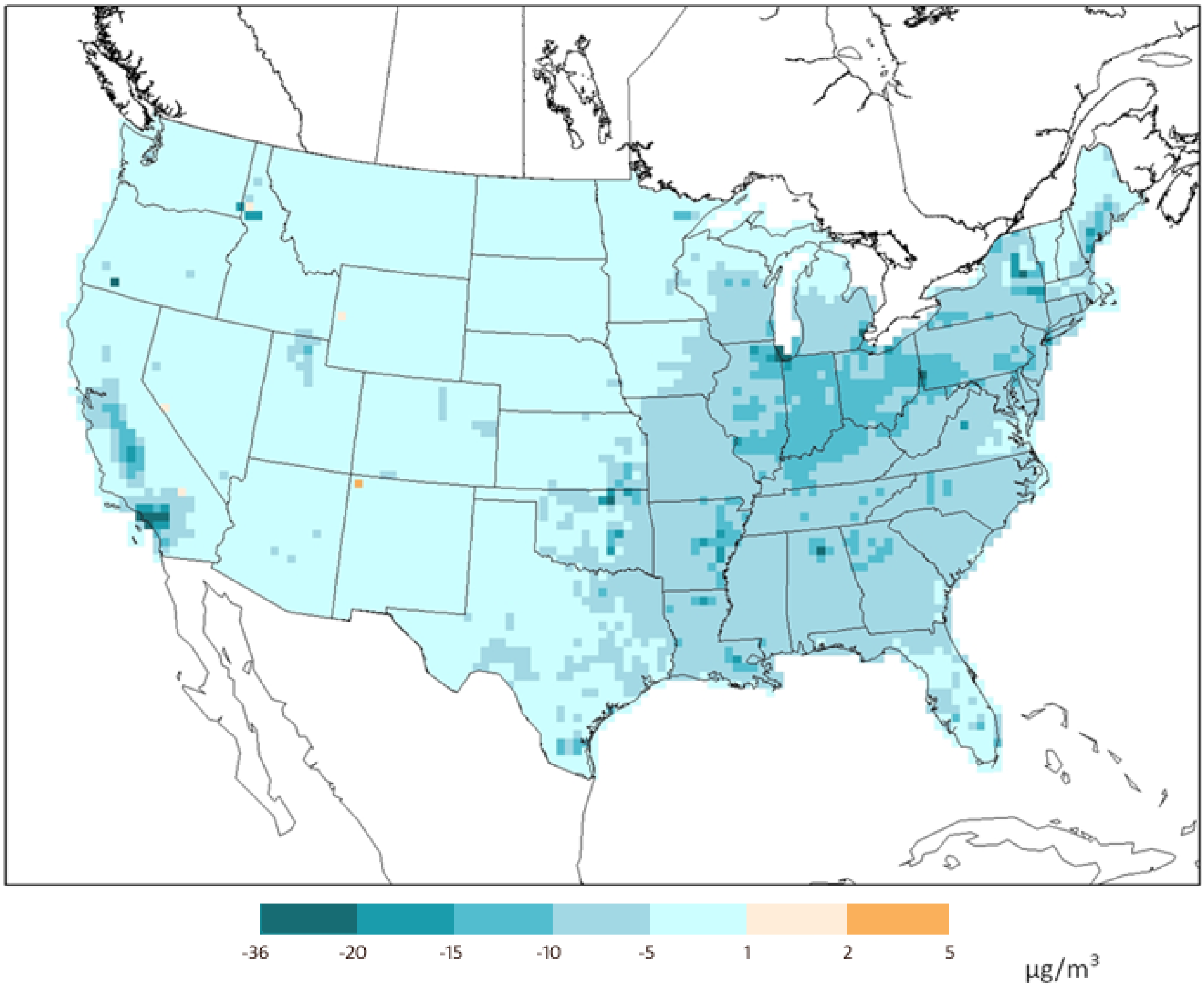

Exhibit 7. Difference in annual average fine particle (PM2.5) concentrations between the *With-CAAA* and *Without-CAAA* scenarios: *With-CAAA* minus *Without-CAAA* for 2020. (In micrograms per cubic meter). The map shows the change in concentrations of fine particles in the atmosphere achieved by 1990 Clean Air Act Amendment programs. The darker the blue color, the greater the improvement in air quality. The few spots of orange on the map are isolated locations where the air quality model projected slightly higher fine particle concentrations under the *With-CAAA* scenario than under the *Without-CAAA* scenario.

compared to the large and widespread overall reductions in fine particle pollution under the *With-CAAA* case.

Ozone concentrations are also significantly lower overall under the *With-CAAA* scenario relative to the *Without-CAAA* scenario. As shown by maps provided in the full report, the patterns of air quality improvements for ozone are similar to those observed for fine particles with widespread regional improvements across the East and improvements in the West occurring predominantly in areas influenced by Southern California population centers.

Health Improvements

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

Fine Particle and Ozone Pollution

The largest reductions in fine particle concentrations are achieved in areas with relatively poor air quality and/or high population density (see Exhibit 7). 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 maximize 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-CAAA* and *Without-CAAA* scenarios are substantial, even dramatic.

For example, as early as 2000, annual average exposures[7] to

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

Exhibit 8. Differences in key health effects outcomes associated with fine particles (PM2.5) and ozone between the *With-CAAA* and *Without-CAAA* scenarios for the 2010 and 2020 study target years. (In number of cases avoided, rounded to 2 significant digits). The table shows the reductions in risk of various air pollution-related health effects achieved by 1990 Clean Air Act Amendment programs, with each risk change expressed as the equivalent number of incidences avoided across the exposed population.

[7] "Average exposure" in this case refers to "population-weighted annual average exposure," which is calculated by dividing the total population exposure over the course of a year by the total number of people in the exposed population. This measure provides a helpful summary indicator of overall exposures and exposure changes, in this case across all people living in the 48 states; though people living in particular locations may experience much higher or much lower exposures or exposure changes than people in other locations. To illustrate, consider a population of three people where two people experience a change in exposure from 30 to 10 micrograms per cubic meter (μg/m^3), and a third person's exposure change is from 25 to 20 μg/m^3. The change in population-weighted average exposure would be (20+20+5) divided by 3 = 15 μg/m^3. While the 15 μg/m^3 change provides a

fine particles among the U.S. population are lower by an average of 5 micrograms per cubic meter under the *With-CAAA* scenario. By 2020, the 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. This 9 microgram per cubic meter reduction is tantamount to cutting exposures almost in half, because the population average exposure for 2020 under the *Without-CAAA* scenario is slightly higher than 19 micrograms per cubic meter.[8]

The large reduction in risk of premature mortality associated with fine particles is the most significant outcome among those listed in Exhibit 8. 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 fine particle and ozone exposure have also been extensively peer-reviewed.

In addition to reductions in incidences of premature mortality,[9] 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 days, and lost school days.

Hazardous Air Pollutants

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 Amendments in reducing benzene emissions and exposures in the Houston area was conducted as part of this study. The study found a significant cancer-reducing benefit overall in the region, but also found that 1990 Clean Air Act Amendment programs led to the most substantial reductions in those areas with the highest baseline cancer risks. These results are described in detail in the full report and in a separate technical report documenting the Houston benzene case study.

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useful measure of the shift in overall population exposure, it may obscure the fact that the third individual experienced a significantly smaller improvement and is left with a significantly higher residual exposure.

[8] For perspective, this level of population-wide annual average fine particle exposure is about the same as that experienced by people living in Los Angeles in the year 2000. (See Text Box 4-1 of the full report.)

[9] The term "incidence" is not intended to represent premature mortality of a particular known individual, but rather small reductions in risk experienced by many people that sum to an aggregate change in population risk numerically equivalent to one avoided premature mortality.

Other Clean Air Act Pollutants

Reductions in ambient concentrations of other Clean Air Act 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 fine particles, are modeled at the same time. Furthermore, health effects of some pollutants 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[10] 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,

Quantified Human Welfare and Ecological Effects	Pollutant(s)
Visibility in residential areas (metropolitan areas)	PM, Ozone
Visibility in recreational areas (large parks in three regions)	PM, Ozone
Commercial timber (commercially important tree species)	PM, Ozone
Agriculture (commercially important crops)	Ozone
Recreational fishing (Adirondacks)	Acid Deposition
Materials damage (a few acid-sensitive materials)	Sulfur Oxides

Exhibit 9. Ecological and welfare effects included in primary estimates of benefits. For each effect in the table, the limited geographic range or the subset of effects included in the primary results is listed in parentheses.

[10] There are six Clean Air Act "criteria pollutants" for which national ambient air quality standards are established: particulate matter, ozone, carbon monoxide, sulfur dioxide, nitrogen oxides, and lead (Pb).

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 9.

In addition to limitations in the range of effects included in the primary results, several of the included effects were subject to limitations in geographic coverage or the number of commodities or ecosystems covered. The limited scope of quantified effects or limited geographic coverage for each effect is described in Exhibit 9. For example, available data and modeling tools supported assessment of the effects of changes in ozone exposure only for select, 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 other areas of the country. This study is therefore subject to the same persistent limitations in data and methods for evaluating potentially important ecological and human welfare outcomes which have impaired 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.

Visibility

Based on measurable economic value, improvements in visibility emerged as one of the most significant non-health effects of better air quality under the *With-CAAA* scenario. A new methodology was applied to estimate the economic value of visibility improvements in metropolitan areas, and the effect of this new approach was to expand the number of locations where visibility improvements could 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 and other federal “Class I” areas.[11] 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-CAAA* and *Without-CAAA* scenarios used to estimate both recreational and residential visibility benefits are shown in Exhibit 10. While benefits are estimated for all target years of the study, Exhibit 10 contrasts the county-level visibility conditions under the *With-CAAA* case relative to the *Without-CAAA* case for the year 2020. Visibility impairment is measured in Deciviews, which is a rating scale aimed at measuring and then valuing perceptible changes in visibility. In Exhibit 10, the darker the color, the greater the impairment

[11] Under the Clean Air Act, a “Class I” area is one in which visibility is protected more stringently than under the national ambient air quality standards. Class I areas include national parks, wilderness areas, monuments, and other areas of special national and cultural significance.

in visibility; so the lighter orange areas in the lower *With-CAAA* map indicate improved visibility resulting from 1990 Clean Air Act Amendment programs.

Previously established methods were used to estimate visibility improvements at federal Class I areas across the U.S. Because of limitations in the applicability of available economic valuation studies, however, the primary estimate of benefits presented herein includes only 86 parks and recreational areas in California, the Southeast, and the Southwest. The total value of visibility improvements at these 86 Class I areas is estimated to reach $19 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. 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.

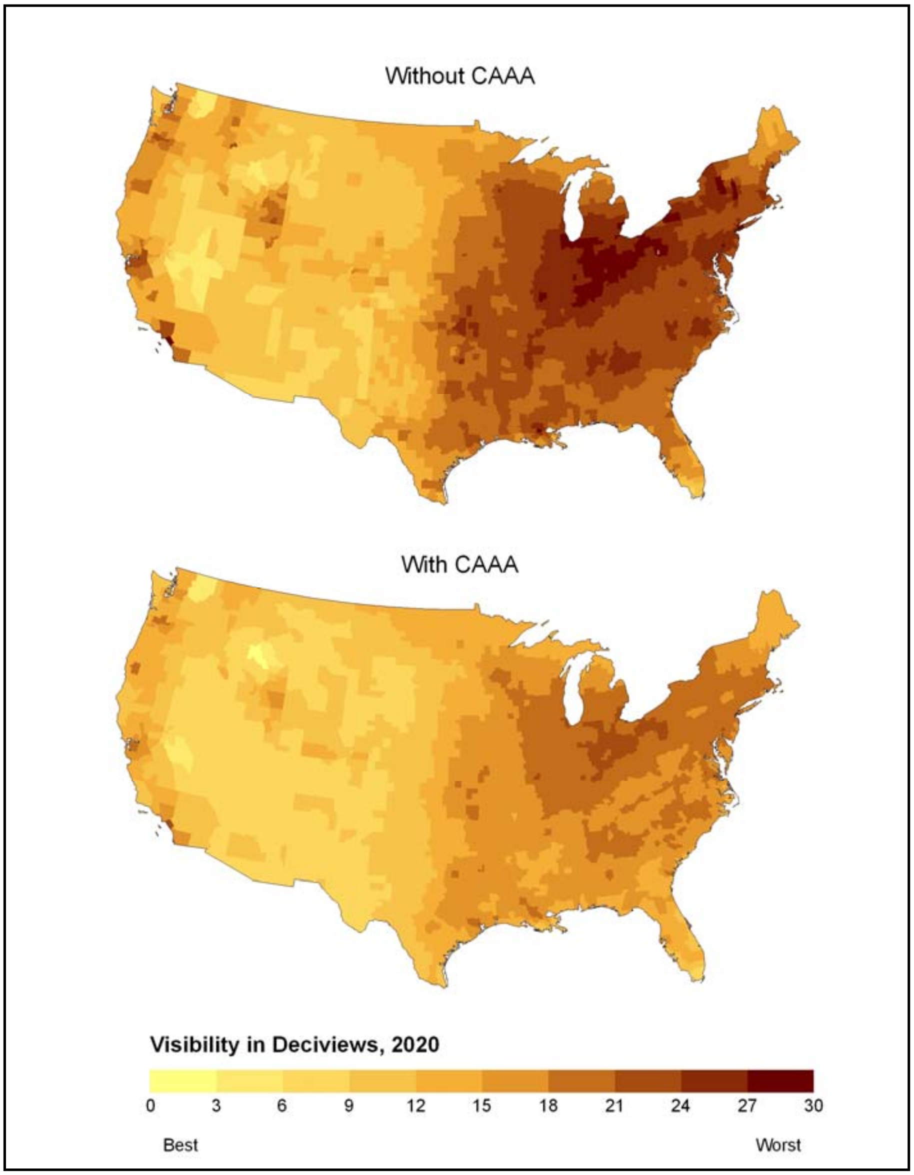

Exhibit 10. Visibility conditions at the county level under the *With-CAAA* and *Without-CAAA* scenarios for 2020. (In Deciviews). The maps show visibility conditions under each scenario with lighter colors indicating better visibility.

Comparison of Direct Costs and Direct Benefits

The final step in the benefit-cost analysis conducted for this study was to express the various health, welfare, and environmental benefits of 1990 Clean Air Act Amendment programs in dollar values so the benefits could be compared to the dollar-based estimates of control costs. As illustrated in Exhibit 11, comparison of the central estimates for benefit and costs supports a conclusion that programs related to the 1990 Clean Air Act Amendments are expected to yield benefits which vastly exceed their costs.

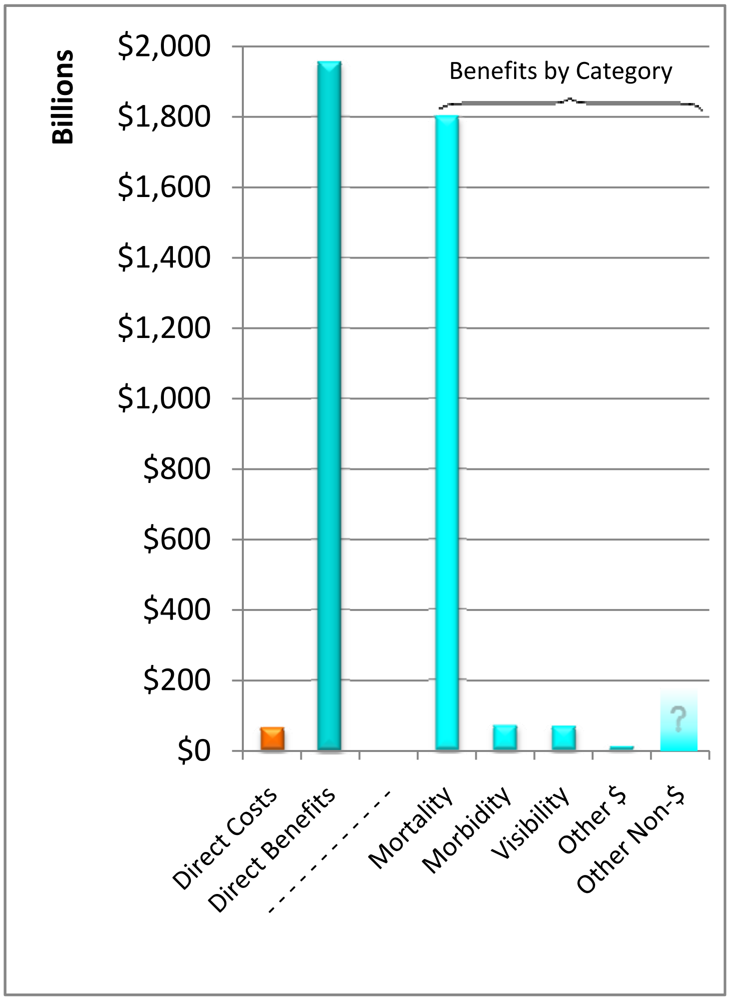

Exhibit 11. Year 2020 Primary Central Estimates of direct costs and direct benefits with breakdown of benefits by effect category. (In billions of year 2006 dollars). The two leftmost bars show the extent to which total benefits exceed total costs, and the bars to the right provide the breakdown of benefits by category of effect. The third bar shows the extent to which mortality reduction benefits exceed all other effects, including total costs. The Other Non-$ bar to the right is intended to emphasize the extensive benefit endpoints which could not be monetized, and the question mark indicates the potential value of these effects is unknown.

EPA is confident that this finding of positive net benefits of 1990 Clean Air Act Amendment programs is robust for several reasons. First, the benefits of improved morbidity and improved visibility alone are more than twice the estimated cost of compliance with 1990 Clean Air Act Amendment requirements; so even if one chose to ignore the substantial reductions in mortality risk achieved by these programs or assigned them a value of zero, benefits would still be projected to exceed costs. Second, many beneficial outcomes involving human health or environmental improvement could not be expressed in terms of economic values because the scientific and economic studies to support such valuations remain inadequate or unavailable. If methods were available to quantify these omitted effects, the estimate of net benefits would further increase. Some components of cost are also subject to uncertainty or omission, but cost uncertainties are comparatively minor in number and significance relative to uncertainties on the benefit side of the ledger. Finally, the in-depth assessment of key uncertainties described in the full report indicates that the chances are extremely small that uncertainties in the analysis could lead to a scenario in which costs exceed benefits.

Those who nevertheless find that uncertainties and other limitations of benefit-cost analysis render these results less than satisfactory for obtaining policy insights may prefer to use other paradigms for measuring, comparing, and evaluating the outcomes projected by this study. For example, it is possible to avoid assigning uncertain dollar-based values to changes in risk of premature mortality and, instead, compare the costs of Clean Air Act programs with the projected number of avoided incidences of premature mortality or illness. 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.

One example of an alternative paradigm for assessing and comparing the value of premature mortality risk reductions achieved by the 1990 Clean Air Act Amendment programs is to divide compliance costs for a given year by the number of incidences of avoided premature mortality

Estimating and Valuing Reductions in Risk of Premature Mortality

Exposure to some forms of air pollution increase a person's chances of experiencing an illness they would not otherwise have experienced, or dying earlier than would otherwise have been expected. For the fine particle pollution which dominates the outcome of this benefit-cost study, changes in health risk differ among individuals based on factors such as age and initial health status. For example, individuals who have already experienced stroke or heart disease may experience a different loss in future life expectancy due to increased exposure to fine particle pollution than others in the population might experience. This variability in risk from a given change in pollution exposure means that different individuals experience different shifts in their "survival curve" which, in the air pollution context, represents the expectations an individual may have for additional years of life as different ages are reached. This variability among different segments of the population complicates efforts to estimate the overall change in risk experienced by the population as a whole following implementation of programs such as those associated with the Clean Air Act.

Moreover, a further complication arises in the context of benefit-cost analyses aimed at gauging the value to society of the reductions in premature mortality risks achieved by these programs. In addition to variability in how different individuals' survival curves shift when fine particle pollution is reduced, different individuals may also assign different values to a given shift in their survival curve. The extents to which people may assign different economic values to mortality risk reductions based on age, initial health status, or the source or nature of the risk (e.g., voluntary versus involuntary, sudden versus protracted) are significant uncertainties.

In the absence of sufficient scientific and economic data and tools for capturing the variability within the population in both the reduction in risk and the value individuals assign to such risk reduction, the estimates for both the population-wide risk change and the overall value to society of the aggregate risk change are uncertain. While the methods used for this study are state-of-the-art and consistent with other recent analyses, the key uncertainties which nevertheless persist in estimating the magnitude and value of changes in mortality risk due to air pollution are discussed and evaluated in detail in this study's full report and in the technical reports on health effects and on uncertainty which accompany this study.

projected to result from that year's emissions reductions. The result of this calculation for *With-CAAA* emission reductions achieved in the year 2020 is about $280,000 per avoided incidence of premature mortality. 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.

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-CAAA* and *Without-CAAA* 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 fine particles 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.

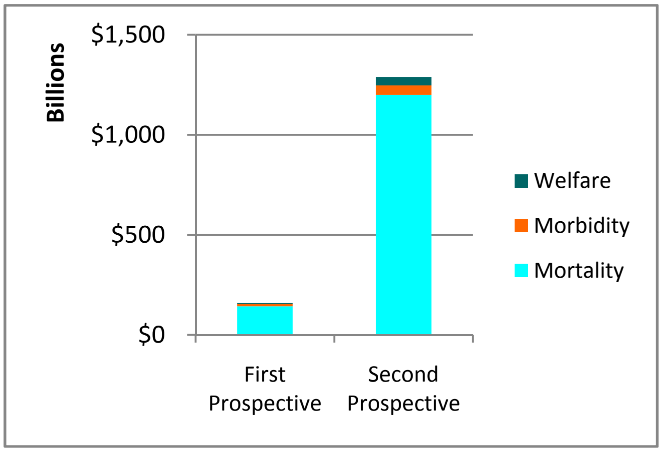

Exhibit 12. Comparison of 2010 Benefits from First and Second Prospective Studies. (In billions of year 2006 dollars)

As shown in Exhibit 12, 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 particles.

Avoiding incidences of premature mortality, especially those associated with exposure to fine particles, contributes the vast majority of the direct benefits of 1990 Clean Air Act programs measured in dollar value terms, as shown in Exhibit 11. There are two principal reasons mortality effects dominate the estimated differences in value between the *With-CAAA* and *Without-CAAA* cases. First, the differences in air quality, human exposure, and resulting risk of premature mortality between the two scenarios are substantial. Second, these changes in risk of premature mortality are estimated to have significant economic value, as measured by studies that 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, with prevailing default values described in longstanding EPA economic guidelines, and with recent EPA Regulatory Impact Analyses. In addition to being consistent with current EPA policy and longstanding EPA practice, the valuation estimates used are close to estimates emerging in recent literature. Nevertheless, assigning appropriate value to premature mortality risk reductions achieved through air pollution control remains a significant challenge as described in the text box entitled *Estimating and Valuing Reductions in Risk of Premature Mortality* and in this study's full report and supporting technical documents.

Other categories of benefits presented in Exhibit 11 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 11 to emphasize that the potential contribution to total benefits of these unquantified effects is simply unknown, but could conceivably be substantial.

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-CAAA* and *Without-CAAA* 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-CAAA* case on sectors which are major consumers of electricity. Therefore, a macroeconomic 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. In addition to estimating changes in overall growth of the economy as measured by Gross Domestic Product (GDP), the macroeconomic model provided estimates of the change in "equivalent variation (EV)"[12] a measure of the economic welfare of individuals or households.

Two macroeconomic model runs were conducted. The first model run evaluated the effect on the overall economy of just the additional cost of air pollution controls under the *With-CAAA* case relative to the *Without-CAAA* case. The second model run incorporated these higher compliance costs but also added in some of the beneficial effects of cleaner air under the *With-CAAA* case; specifically, improvements in labor force participation and productivity, and savings on costs of treating air pollution-related illnesses.

While the key outcomes of changes in overall economic growth and in household economic welfare are presented in this summary report, the full set of modeling results, including the changes in output from each of the economic sectors covered by the macroeconomic model, are presented in the full report and supporting technical document.

Macroeconomic Model Run A: Compliance Costs Only

The first macroeconomic model run 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-CAAA* scenario on prices and quantities of goods and services produced and consumed by different sectors, including households and various categories of industrial activity.

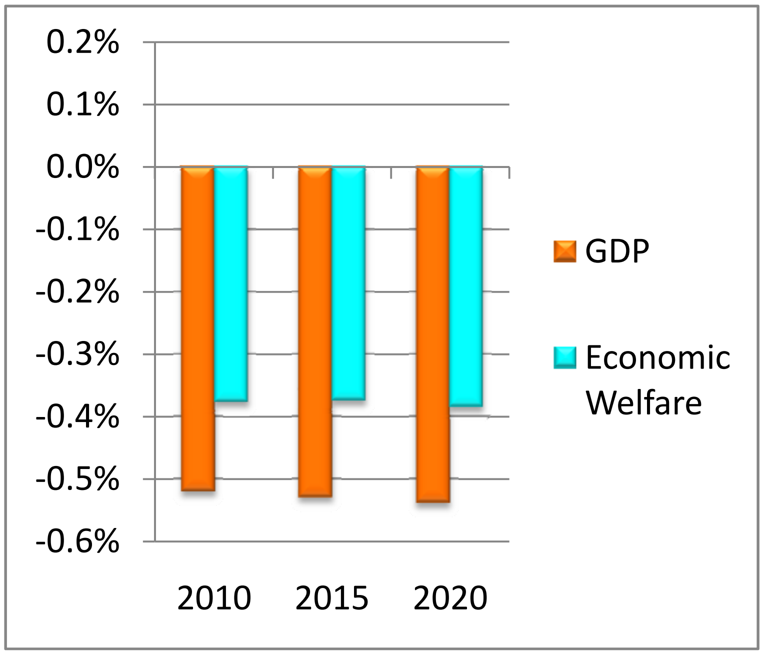

Exhibit 13. Differences in "Cost Only" model projections of GDP and economic welfare between the *With-CAAA* and *Without-CAAA* scenarios. For the set of economy-wide model runs which excluded beneficial effects of clean air, the orange bars indicate that economic growth as measured by Gross Domestic Product is lower throughout the study period. The blue bars indicate that the measure of economic welfare generated by the economy-wide model is also lower through the end of the study's reference period.

[12] "Equivalent variation" is an economic term for the amount of money someone would pay to avoid a change in prices or other market conditions which affect their economic well-being. In the present context, it provides a measure of the total value that people participating in the formal economy would assign to changes in markets for goods and services, including their own labor, associated with implementation of the 1990 Clean Air Act Amendments. Important limitations in this measure of welfare are described in the text box entitled *Measuring "Economic Welfare."*

The key overall results of the "Cost Only" run are shown in Exhibit 13. These key effects include both changes in overall 2010 to 2020 economic growth resulting from the investments made in Clean Air Act programs between 1990 and 2020, and the effect of changes in growth and sector-specific activity on the economic welfare of households. The results for the "Cost Only" run show that economic growth is about 0.54% lower in the year 2020 under the *With-CAAA* scenario than under the *Without-CAAA* scenario, mostly due to the effects of higher energy costs on various sectors of the economy. The macroeconomic model's measure of household economic welfare in 2020 is lower under the *With-CAAA* scenario by about 0.39%. The household welfare change 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 economic 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 incur a small decrease in economic well-being, though there are important limitations in the macroeconomic model's measure of household economic welfare. (See the text box entitled *Defining "Economic 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 household medical expenditures for air pollution-related health problems, and protects the quality of the environment on which economic activity and growth depend.

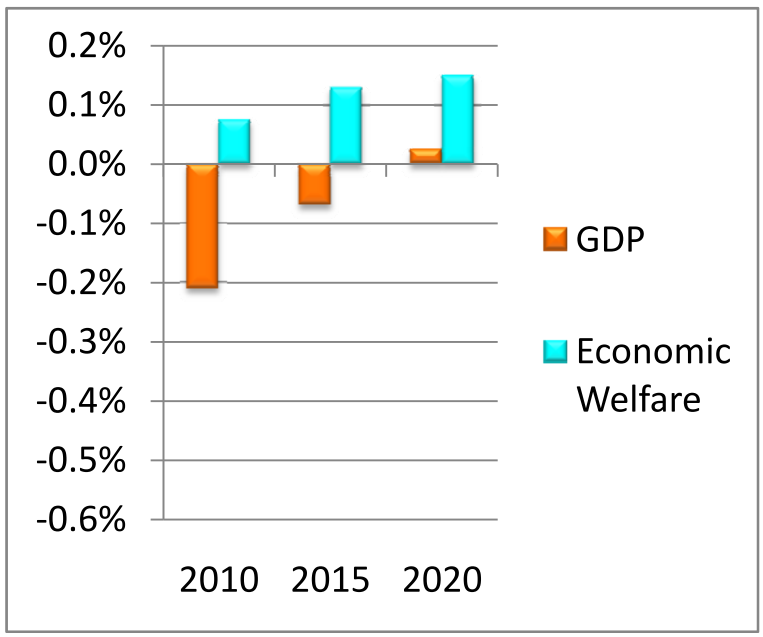

Exhibit 14. Differences in "Labor Force-Adjusted" model projections of GDP and economic welfare between the *With-CAAA* and *Without-CAAA* scenarios. A comparison of this chart with the preceding one (Exhibit 13) shows the significant changes in economy-wide modeling which occurred when just two of the beneficial effects of clean air were incorporated. Economic growth as depicted by the orange bars is initially lower but by the end of the study period 1990 Clean Air Act Amendment programs lead to higher overall growth in the economy. The blue bars indicate growing improvement in the measure of household economic welfare, a result which occurs because of the two beneficial effects of cleaner air and the fact that welfare is not determined by economic growth alone. Including more of the beneficial effects of cleaner air would likely result in even greater improvements in economic growth and household economic welfare.

Macroeconomic Model Run B: Adding Labor Force Improvements and Avoided Medical Costs

This study, for the first time, attempts to capture the broader economic effect of at least some of the benefits along with all of the estimated direct costs of 1990 Clean Air Act Amendment 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-CAAA* scenario.

Exhibit 14 shows the results for the "Labor Force-Adjusted" macroeconomic modeling of the *With-CAAA* and *Without-CAAA* scenarios, and the results are very different from those obtained from the "Cost Only" model runs. By capturing some of the benefit-side effects, GDP eventually improves overall, and the measure of household economic welfare change 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%. 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.

Measuring "Economic Welfare"

The formal, measured economy –as represented in this study's economy-wide model–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 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. Therefore, 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.

Uncertainties

Benefit-cost studies of environmental programs are often highly complex, involve limited or uncertain scientific and economic data, and rely on models and other tools to simulate real world processes such as the atmospheric dispersion, transformation, and transport of air pollutants. Furthermore, external factors and conditions –such as rates of technology change or shifts in geographic patterns of economic activity—may also influence estimates of the benefits and costs of air pollution control programs. To meet the analytical challenges posed by these complexities and uncertainties, this study applied the best available data and modeling tools, and used an extensive three-step approach to identify uncertainties and assess how they might influence the study's results.

For each major analytical step, beginning with development of emissions inventories and continuing through economic valuation of effects, potentially significant sources of uncertainty in the benefit and cost estimates were identified. Each "source of potential error" was evaluated to assess the direction and potential magnitude of its influence on the study's results. For some factors, alternative data or models were available which could be used to measure uncertainty in quantitative terms. Using quantitative methods where they were available –and analyst judgment where they were not—sources of potential error were classified as major or minor depending on whether reasonable shifts in their value could change the study's overall estimate of net benefits by more or less than five percent.

On the cost side, a number of uncertainties were identified, including cost components which are known to exist but could not be quantified, and cost components which were included but involve uncertain factors. As an example of an omitted effect, this study does not attempt to quantify the effect of clean air programs on the quality or features of affected products, such as the surface adhesion properties of paint reformulated to reduce emissions of volatile organic compounds. On the other hand, potential beneficial effects of product reformulation or redesign were also excluded. Staying with the example of paint reformulation, the study also omits the benefit of reducing indoor exposures to volatile organic compounds which are toxic.

Among the cost components which could be quantified, key uncertainties include the costs incurred by areas projected to need emissions reductions beyond those achievable by known cost-effective control measures, the effects on compliance cost of increasing industry experience with a given technology (i.e., "learning effects") as well as the effects of more fundamental technology change, and estimates of the percentage of vehicles failing to meet vehicle inspection and maintenance (I&M) requirements. In the end, however, none of the identified uncertainties on the cost side were classified as major. This is because total benefits exceed total costs by such a large margin that even doubling the total cost estimate would change the study's estimate of net benefits by less than five percent.

The list of effects on the benefit side which were only partially quantified, or entirely omitted, is far more extensive. Uncounted benefits 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, such as enhanced recreational experiences resulting from healthier forests. A variety of known or suspected human health effects associated with fine particle, ozone, or other Clean Air Act criteria pollutants were also excluded from this study's quantitative results due to limitations in health effects data, economic valuation information, or both.

There were also many more uncertainties identified for quantified benefits than for quantified costs. The complete list of uncertainties identified on the benefit side is available in the full report, but the three which emerged as the most significant were related to the estimated change in premature mortality risk resulting from fine particle exposure, the choice of model for estimating the timing of premature mortality risk changes following a change in fine particle exposure,[13] and the estimated economic value of reducing premature mortality risk from air pollution. All three of these factors, along with eleven others associated with benefits estimation, were found to meet the study's criterion for defining a major uncertainty.

In the third step of the three-step uncertainty analysis, the effects of several of the most important quantifiable uncertainties were assessed using simulation modeling techniques. The results provide useful insights about which uncertain factors are most important and how the results of the study might be interpreted given the combined effect of these uncertainties. The detailed results of the simulation modeling and other uncertainty tests, along with discussion of the insights gained, are available in the full report and the supporting technical report on uncertainty analysis. In essence, the results suggest that it is extremely unlikely the costs of 1990 Clean Air Act Amendment programs would exceed their benefits under any reasonable combination of alternative assumptions or methods which could be identified. Even if one were to adopt the extreme assumption that fine particle and ozone pollution have no effect on premature mortality risk –or that such risk reductions occur but they have no value— the benefits of reduced non-fatal health effects and improved visibility alone add up to $137 billion for the year 2020, an amount which is more than twice the estimated $65 billion cost to comply with all 1990 Clean Air Act Amendment requirements in that year.

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 their direct costs, which means economic welfare and quality of life for Americans were improved by passage of the 1990 Amendments and implementation of programs to meet their requirements.*** The wide margin by which benefits exceed costs combined with extensive uncertainty analysis suggest it is very unlikely this result would be reversed by any reasonable combination of alternative assumptions which could have been adopted in this study.

[13] "Cessation lag" is the technical term used to describe the delay between the change in air pollution exposure and the resulting change in health outcomes. Models for cessation lag which assume that a substantial proportion of the risk reduction occurs many years after the air quality improvement can lead to significantly lower estimates for the economic value of that improvement. Conversely, cessation lag models which assume most or all of the risk reduction occurs shortly after the air quality change can result in higher benefit estimates.

2. ***The broader economy is also improved overall by the 1990 Clean Air Act Amendments and related programs.*** While virtually all the costs of these programs could be incorporated, only two beneficial effects of cleaner air could be captured in the economy-wide model: improvements in worker productivity due to improved health, and savings on costs of medical care for some pollution-related health problems. Nevertheless, these two beneficial effects alone more than offset the economy-wide costs of investing in air pollution controls as both overall economic growth and the measurable economic welfare of American households are shown to be improved by the 1990 Clean Air Act Amendments.

3. ***Persistent uncertainties and limitations in available data and methods mean that some elements of cost and many human health, human welfare, and ecological effects cannot be fully and effectively captured in benefit-cost studies of air pollution control programs.*** The relatively comprehensive scope of the present study and its extensive uncertainty analysis highlight these deficiencies and demonstrate the need for ongoing investments in scientific and economic research to improve estimates of clean air program benefits and costs.

4. ***After designing, implementing, and evaluating the results of the current study, the Project Team identified several potential improvements worth considering for future analytical efforts.*** As described in the next section, future evaluation of Clean Air Act programs might be improved through scenarios analysis or an expanded 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 research. Second, the lessons learned from this study may provide insights which help improve the design of future studies and methods development efforts.

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 its analysis of energy externalities (see National Research Council, *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*, June 2010).[14] 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.

[14] Available at http://www.nap.edu/openbook.php?record_id=12794

Data, methods, and modeling tools

The 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, the macroeconomic modeling techniques used to account for beneficial as well as costly effects of pollution control could be further refined and adapted to improve the modeling of economy-wide effects of other environmental programs.

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 that 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[15] air quality alerts for ozone. Ozone air quality alerts may in turn lead to a reduction in outdoor activity, which may lead to greater use of indoor air conditioning. As people increase their use of air conditioners, the resulting increase in demand for electricity may lead to higher fine particle emissions from electricity generating units. A scenarios analysis approach might also support more realistic modeling 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 realistic and consistent manner include patterns of economic growth, rates of technological development, patterns and intensity of fuel use, changes in atmospheric conditions, and population behavioral responses to air pollution and to measures taken to control it.

Value of Information analysis

Formal Value of Information (VOI) analysis has rarely been applied in evaluations of air pollution control programs. VOI 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.

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[15] Code red days are those classified under the Air Quality Index (AQI) as "unhealthy." For ozone code red days EPA recommends that sensitive groups avoid, and everyone else should limit, prolonged or heavy outdoor exertion. For more information about the AQI, go to http://www.epa.gov/airnow/aqi_brochure_08-09.pdf.

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 also 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 not currently addressed by Clean Air Act programs so the potential value of addressing such pollutants is clarified for policymakers and the public.

Cheaper, faster, better

Benefit-cost analyses of air pollution control programs are enormously complicated exercises, usually requiring operation of a long chain of highly complex models with numerous, large data sets. The substantial time and resource costs of the modeling systems used in the present study precluded the multiple model system runs that could provide 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 resources 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 considerable, so 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 (see Exhibit 3 above). 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 confront at least two significant challenges. First, the Retrospective Study used data and modeling tools 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. Second, 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 compounds and other emissions beyond the reductions achieved by programs under 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 both 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 Amendments 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-CAAA* scenario are significantly worse than projected under the *With-CAAA* case. As a result, 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 a world without all the federal, state, and local programs implemented after passage of the 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 air quality improvements and resulting net benefits estimated by this study.

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 Clean Air Act as amended in 1990 versus a hypothetical, counterfactual state of the world without the 1990 Amendments. 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 48 contiguous states. It therefore does not provide the analyses of location-specific meteorological data, control measures, and consecutive year air quality change used to determine attainment with air quality standards. Nevertheless, the study does provide insights on the overall magnitude of 1990 Clean Air Act Amendments compliance costs and the substantial benefits achieved by the measures taken.

The significant benefits estimated for 1990 Clean Air Act Amendment-related programs can be traced to the large differences between actual air quality conditions reflected in the* With-CAAA *case and the much poorer air quality conditions projected under the counterfactual* Without-CAAA *case. Are those poor air quality conditions under the counterfactual scenario realistic?

While the *With-CAAA* air quality conditions are anchored to actual air quality monitor data, the air quality conditions under the hypothetical *Without-CAAA* scenario cannot be observed and therefore the credibility of those projected conditions is harder to establish. Comparisons to historical conditions can be helpful, but in this case such comparisons are confounded for the fine particle pollution which dominates this study's results because the particle size fractions monitored through the years changed. Nevertheless, data were available for a few time periods and locations where both fine ($PM_{2.5}$) and coarse particle fractions –PM_{10} and/or Total Suspended Particles (TSP)—were monitored. These data showed that projections for *Without-CAAA* air quality in three of the four U.S. cities examined were reasonably consistent with historical monitored air quality during the 1980 to 1990 period prior to passage of the 1990 Clean Air Act Amendments, suggesting that *Without-CAAA* air quality conditions are severe but plausible. For example, despite a significant deterioration in Los Angeles air quality under the *Without-CAAA* scenario, the projected annual average PM2.5 concentration for 2020 of 35.5 micrograms per cubic meter is slightly less than Los Angeles' estimated 1980 annual average PM2.5 concentration of 38.5 micrograms per cubic meter. Details of these comparisons are available in the full report (see text box 4-1).

Some of EPA's previous analyses of particular rules included an assumption that there was no mortality-related benefit from reducing exposure to fine particle pollution once concentrations fell below some threshold level. Does this study apply a threshold assumption?

In a limited number of past analyses of individual rulemakings, EPA did impose an assumption that there was no further benefit to reducing fine particle exposures once concentrations to which people were exposed fell below 10 micrograms per cubic meter. However, based on a subsequent re-assessment of the scientific literature and consultation with the public and outside experts, EPA returned to the earlier practice of estimating benefits down to the lowest measured fine particle concentrations without imposing an assumed threshold. This is the same approach used in the first two reports in this series: the Retrospective Study and the First Prospective Study. EPA nevertheless believes there is a distinction which can be made between exposure changes which occur above versus below the fine particle concentrations measured in the health studies used to estimate benefits. Although a health study's lowest measured level (LML) is not viewed as a threshold, EPA's confidence in benefit estimates is higher for the portion of the risk change which occurs at or above the LML of a health study used to estimate benefits. For the fine particle-related premature mortality benefits presented herein, two health studies were applied. The LML of the Laden et al. (2006) study is 10 micrograms per cubic meter, and 91 percent of the mortality risk reduction benefit presented in this analysis occurs at or above this concentration. Similarly, the corresponding numbers for the Pope et al. (2002) study are 7.5 micrograms per cubic meter and 98 percent of the estimated mortality reduction benefit. Given that the vast majority of the present study's mortality risk reduction occurs at or above the LMLs of the underlying health studies, EPA's confidence in the estimates of the fine particle-related premature mortality benefits presented herein is particularly high.

The Second Prospective Study results are dominated by the benefits of reducing overall exposures to fine particles. 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 particles are more toxic than others?

As a practical matter, the mix of particle species making up total fine particle mass does not change much between the *With-CAAA* and *Without-CAAA* scenarios. Therefore, the results presented herein would not be very sensitive to even strong assumptions about potential differences in the toxicity of particle species. Furthermore, 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 fine particle exposure and health effects such as premature mortality are based on aggregate measures of fine particle 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.

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 fine particle-related premature mortality. The difference in health outcomes with and without 1990 Clean Air Act Amendment 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 Amendment programs. Instead, as shown by the direct cost results of this study, the costs to society of implementing these programs only reach about $190 per person by 2020, the study year when the incremental costs are highest. The $6,000 figure is a dollar-based value for the welfare improvement people enjoyed by avoiding the poor air quality conditions projected under the *Without-CAAA* 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 Amendment programs.

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

When EPA defined the scope of the study in 2001, there were no Clean Air Act standards in place which specifically address greenhouse gas emissions, nor were there any Agency plans at that time to set such standards in the future. Furthermore, the final specification of scenarios to be analyzed was made in 2005, two years before the 2007 Supreme Court ruling that greenhouse gases are pollutants covered by the Clean Air Act. Although not included within the scope of this study, EPA has conducted numerous other 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.

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