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The Benefits and Costs of the Clean Air Act 1990 to 2010

EPA Report to Congress

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Executive Summary

Section 812 of the Clean Air Act Amendments of 1990 requires the Environmental Protection Agency to periodically assess the effect of the Clean Air Act on the "public health, economy, and environment of the United States," and to report the findings and results of its assessments to the Congress. This Report to Congress, the first of a series of prospective studies we plan to produce every two years, presents the results and conclusions of our analysis of the benefits and costs of the Clean Air Act during the period from 1990 to 2010. The main goal of this report is to provide Congress and the public with comprehensive, up-to-date information on the Clean Air Act's social costs and benefits, including improvements in human health, welfare, and ecological resources.

The first report that the EPA created under the section 812 authority, The Benefits and Costs of the Clean Air Act: 1970 to 1990, was published and conveyed to Congress in October 1997. This retrospective analysis comprehensively assessed the benefits and costs of all requirements of the 1970 Clean Air Act and the 1977 Amendments, up to the passage of the Clean Air Act Amendments of 1990. The results of the retrospective analysis showed that the nation's investment in clean air was more than justified by the substantial benefits that were gained in the form of increased health, environmental quality, and productivity.

The Clean Air Act Amendments of 1990 built upon the significant progress made by the original Clean Air Act of 1970 and its 1977 amendments in improving the nation's air quality. The amendments utilized the existing structure of the Clean Air Act, but strengthened those requirements to tighten and clarify implementation goals and timing, increase the stringency of some requirements, revamp the hazardous air pollutant regulatory program, refine and streamline permitting requirements, and introduce new programs for the control of acid rain precursors and stratospheric ozone depleting substances. Because the 1990 Amendments represent an incremental improvement to the nation's clean air program, the analysis summarized in this report was designed to estimate the costs and benefits of the 1990 Amendments incremental to those assessed in the retrospective analysis. Our intent is that this report and its predecessor, the retrospective, together provide a comprehensive assessment of current and expected future clean air regulatory programs and their costs and benefits.

This first prospective analysis consists of a sequence of six steps. These six steps, listed in order of completion, are:

(1) estimate air pollutant emissions in 1990, 2000, and 2010;
(2) estimate the cost of emission reductions arising from the Clean Air Act Amendments;
(3) model air quality based on emissions estimates;
(4) quantify air quality related health and environmental effects;
(5) estimate the economic value of cleaner air; and
(6) aggregate results and characterize uncertainties.

The methodology and results for each step are summarized below and described in detail in the chapters of this report.

Air Pollutant Emissions

Estimation of reductions in pollutant emissions afforded by the 1990 Clean Air Act Amendments (CAAA) serves as the starting point for this study's subsequent benefit and cost estimates. We focused our emissions analysis on six major pollutants: volatile organic compounds (VOCs), nitrogen oxides

(NO_x), sulfur dioxide (SO_2), carbon monoxide (CO), coarse particulate matter (PM_{10}), and fine particulate matter ($PM_{2.5}$). For each of these pollutants we forecast emissions for the years 2000 and 2010 under two different scenarios: a) the Pre-CAAA scenario that assumes no additional control requirements would be implemented beyond those that were in place when the 1990 CAAA were passed; and b) the Post-CAAA scenario that incorporates the effects of controls which, when we formulated the scenario, we expected would be likely to occur as a result of implementing the 1990 Amendments. Emissions estimates for both the Pre-CAAA and Post-CAAA scenarios reflect expected growth in population, transportation, electric power generation, and other economic activity by 2000 and 2010. We compare the emissions estimates under each of these scenarios to estimate the effect of the CAAA requirements on future emissions.

The results of the emissions phase of the assessment indicate that the 1990 Clean Air Act Amendments significantly reduce future emissions of air pollutants. Substantial reductions will be achieved for the two major precursors of ambient ground-level ozone: volatile organic compounds (VOCs) and oxides of nitrogen (NO_x). Relative to the Pre-CAAA scenario, estimated VOC emissions under the Post-CAAA case are 35 percent lower by 2010. This change in emissions is due largely to VOC reductions from motor vehicles and area sources (e.g., dry cleaners, commercial bakeries, and other widely dispersed sources).

The NO_x emission reduction under the Post-CAAA scenario represents the greatest proportional emissions change estimated in our analysis. For the year 2010, the Post-CAAA NO_x emissions estimate is 39 percent lower than the Pre-CAAA estimate, representing a decrease in emissions of almost 11 million tons. Nearly half of this reduction is from utilities, largely as a result of the particular NO_x emissions cap and trading program we assumed under the Post-CAAA scenario. The remaining reductions are attributable to cuts in motor vehicle and non-utility point source emissions.

Carbon monoxide (CO) emissions contribute directly to concentrations of carbon monoxide in the environment. The 2010 Post-CAAA estimate for CO emissions is 81.9 million tons, 23 percent lower than the Pre-CAAA projection. The reduction in CO emissions is mostly due to motor vehicle emission controls.

The CAAA also will achieve a substantial reduction in precursors of fine particulate matter ($PM_{2.5}$). Sulfur dioxide (SO_2) is an important precursor of PM. By 2010, SO_2 emissions are 31 percent lower under the Post-CAAA scenario. Of the 8.2 million ton difference between Pre- and Post-CAAA SO_2 estimates, 96 percent is attributable to additional control of utility emissions through a national cap-and-trade program involving marketable SO_2 emission allowances. Oxides of nitrogen, discussed above, are also important fine PM precursors.

We project the 1990 Clean Air Act Amendments to have more modest effects on emissions of particulate material which is emitted in solid form (i.e., "primary" or "direct" PM_{10} and $PM_{2.5}$ emissions). Overall, emissions of primary PM_{10} and $PM_{2.5}$ are each approximately four percent lower in 2010 under the Post-CAAA scenario than under the Pre-CAAA scenario. Although the incremental effects of the Clean Air Act Amendments on primary PM emissions will be relatively small, PM in the atmosphere is comprised of both directly emitted primary particles and particles that form in the atmosphere through secondary processes as a result of emissions of SO_2, NO_x, and organic compounds. These PM species, formed by the conversion of gaseous pollutant emissions, are referred to collectively as "secondary" PM. Because, as noted above, the 1990 Amendments achieve substantial reductions in these gaseous precursor emissions, the Amendments have a much larger effect on PM_{10} and $PM_{2.5}$ levels in the atmosphere than might be apparent if only the changes in directly emitted primary particles are considered.

Compliance Costs

Our estimate of the costs of the Clean Air Act Amendment provisions is based on an evaluation of the increases in expenditures incurred by various entities to meet the additional control requirements incorporated in the Post-CAAA case. These costs include operation and maintenance (O&M) expenditures —which includes research and development (R&D) and other similarly recurring expenditures— plus amortized capital costs (i.e., depreciation plus interest costs associated with the existing capital stock). Relative to the Pre-CAAA case, Post-CAAA scenario total annual compliance costs for Titles I through V are approximately $19 billion higher by the year 2000, rising to $27 billion by the year 2010.

Compliance with Title I, Provisions for Attainment and Maintenance of National Ambient Air Quality Standards (NAAQS), accounts for $14.5 billion, or over half, of the estimated increase in year 2010 compliance costs. Compliance with mobile source emissions control provisions under Title II of the Clean Air Act Amendments accounts for an additional 30 percent of the total costs, or $9 billion annually by 2010. Provisions to control acid deposition and emissions of stratospheric ozone depleting substances account for most of the remainder of the costs.

These direct compliance costs provide a good, but incomplete, measure of the total effect of the Clean Air Act Amendments on the U.S. economy. A complete picture of the indirect impacts of these costs would include changes in employment and prices as well as impacts that might be experienced among customers of the firms that must incur these costs. While these indirect effects could be important, we believe the direct cost estimates provide a good initial measure of the effect of the Clean Air Act Amendments on the U.S. economy, as well as an appropriate metric for comparison with the direct benefits reported here.

Table ES-1
Summary Comparison of Benefits and Costs (Estimates in millions 1990$)

	Titles I through V	
	Annual Estimates	
	2000	**2010**
Monetized Direct Costs:		
Low [a]		
Central	$19,000	$27,000
High [a]		
Monetized Direct Benefits:		
Low[b]	$16,000	$26,000
Central	$71,000	$110,000
High[b]	$160,000	$270,000
Net Benefits:		
Low	($3,000)	($1,000)
Central	$52,000	$83,000
High	$140,000	$240,000
Benefit/Cost Ratio:		
Low[c]	less than 1/1	less than 1/1
Central	4/1	4/1
High[c]	more than 8/1	more than 10/1

[a] The cost estimates for this analysis are based on assumptions about future changes in factors such as consumption patterns, input costs, and technological innovation. We recognize that these assumptions introduce significant uncertainty into the cost results; however the degree of uncertainty or bias associated with many of the key factors cannot be reliably quantified. Thus, we are unable to present specific low and high cost estimates.

[b] Low and high benefits estimates are based on primary results and correspond to 5th and 95th percentile results from statistical uncertainty analysis, incorporating uncertainties in physical effects and valuation steps of benefits analysis. Other significant sources of uncertainty not reflected include the value of unquantified or unmonetized benefits that are not captured in the primary estimates and uncertainties in emissions and air quality modeling.

[c] The low benefit/cost ratio reflects the ratio of the low benefits estimate to the central costs estimate, while the high ratio reflects the ratio of the high benefits estimate to the central costs estimate. Because we were unable to reliably quantify the uncertainty in cost estimates, we present the low estimate as "less than X," and the high estimate as "more than Y", where X and Y are the low and high benefit/cost ratios, respectively.

Human Health and Environmental Benefits

To estimate benefits, the results of the emissions analysis served as the principal input to a linked series of models. We used these models to estimate changes in air quality, human health effects, ecological effects, and, ultimately, the net economic benefits of the Clean Air Act Amendments. The goals of these steps in the analysis were to estimate the implications of changes in emissions resulting from compliance with the Clean Air Act Amendments on criteria pollutant air quality throughout the lower 48 states, and the impacts on human health and the environment that result from these changes.

We focused our air quality modeling efforts on estimating the impact of Pre- and Post-CAAA emissions on ambient concentrations of ozone, PM_{10}, $PM_{2.5}$, SO_2, NO_x, and CO and on acid deposition and visibility in future years. We found that the majority of the total monetized benefits, however, is attributable to changes in particulate matter concentrations and, more specifically, to the effect of these ambient air quality changes on avoidance of premature mortality. We estimate that 2010 Post-CAAA PM_{10} and $PM_{2.5}$ concentrations in the eastern U.S. will average about 5 to 10 percent lower than 2010 Pre-CAAA concentrations, with some areas of the eastern U.S. experiencing much greater reductions of up to 30 percent. The air quality modeling also indicates a substantial overall reduction in future-year PM_{10} and $PM_{2.5}$ concentrations throughout the western U.S., including most population centers, following implementation of the Clean Air Act Amendments.

The direct benefits of the air quality improvements we estimated under the Post-CAAA scenario include reduced incidence of a number of adverse human health effects, improvements in visibility, and avoided damage to agricultural crops. The estimated annual economic value of these benefits in the year 2010 ranges from $26 to $270 billion, in 1990 dollars, with a central estimate, or mean, of $110 billion. These estimates do not include a number of other potentially important effects which could not be readily quantified and monetized (i.e., converted to dollar terms). These excluded effects include a wide range of ecosystem changes, air toxics-related human health effects, and a number of additional health effects associated with criteria pollutants.

In addition, these results reflect the particular choices we made with respect to interpretations of the available scientific and economic literature and adoption of paradigms for representing health and environmental changes in economic terms. We refer to these results, then, as our "primary" estimates; however, in the text of this report we also present some alternative results which reflect other available choices for models or assumptions.

One particularly important assumption of our primary analysis is that correlations between increased air pollution exposures and adverse health outcomes found by epidemiological studies indicate causal relationships between the pollutant exposures and the adverse health effects. Future research may lead to revisions in this assumption as well as other key assumptions, data, and models we use to estimate the benefits and costs of the Clean Air Act. Such revisions may in turn imply significant changes in the estimates of Clean Air Act costs and benefits presented here and in past and future assessments. In our judgment, however, the primary results reflect the best currently available science and the most up-to-date tools and data we had at our disposal — and the most reasonable assumptions we could adopt— as each step of the analysis was implemented.

Cleaner air also yields benefits to ecological systems. This first section 812 prospective analysis devotes a great deal of effort to characterizing and, where possible, quantifying and monetizing the impacts of air pollutants on natural systems. Our increased effort is in part a result of the findings of the retrospective analysis, where we identified a better understanding of ecological effects as an important research direction for the first prospective and subsequent analyses. Quantified benefits of CAAA programs reflected in the overall monetized benefits include: increased agricultural and timber yields; reduced effects of acid rain on aquatic ecosystems; and reduced effects of nitrogen deposited to coastal estuaries. Many ecological benefits, however, remain difficult or impossible to quantify, or can only be quantified for a limited geographic area. The magnitude of quantified benefits and the wide range of unquantified benefits nonetheless suggest that as we learn more about ecological systems and can conduct more comprehensive ecological benefits assessments, estimates of these benefits could be substantially greater.

We developed separate estimates for the Title VI provisions of the CAAA designed to protect stratospheric ozone. Stratospheric ozone is the layer of the atmosphere that protects the planet from the harmful effects of ultraviolet radiation (UV-b). Our primary estimate of the cumulative benefits of Title VI is $530 billion. Using the same uncertainty estimation procedure as for other parts of the analysis, we estimate Primary Low and Primary High estimates of $100 billion to $900 billion, respectively. These estimates partially reflect potential averting behaviors, such as remaining indoors or increasing use of sunscreens or hats, which may mitigate the effects of the UV-b exposure increases estimated in the Pre-CAAA case.

Comparing Costs to Benefits

Based on the specific tools and techniques we employed, our primary estimate of the net benefit (benefits minus costs) over the entire 1990 to 2010 period of the additional criteria pollutant control programs incorporated in the Post-CAAA case is $510 billion. Our results imply that the monetizable benefits alone exceeded the direct compliance costs by four to one. For many of the factors contributing to this net benefit estimate (especially physical effects and economic valuation estimates), we were able to generate quantitative estimates of uncertainty. By statistically combining these uncertain estimates, we were able to develop a range of net benefit estimates which provide a partial indication of the overall uncertainty surrounding the central estimate of net benefits. This range, reflecting a 90 percent probability range around the mean, or central estimate, is negative $20 billion (implying a small probability that costs could exceed monetized benefits) to positive $1.4 trillion.

The estimates for Title VI also indicate that cumulative benefits ($500 billion) well exceed cumulative costs ($27 billion). The time period of our Title VI analysis (175 years) suggests that these estimates are very uncertain. Nonetheless, the conclusion that benefits well exceed costs holds even at our Primary Low estimate of benefits (the low end of the 90 percent probability range, or $100 billion), and regardless of discount rate used to generate the cumulative estimates from the perspective of the present.

The assumptions necessitated by data limitations, by the current state of the art in each phase of the analytical approach, by the need to predict future conditions, and by the state of current research on air pollution's effects imply that both the mean estimate and the 90 percent probability range around the central estimate are uncertain. While alternative choices for data, models, modeling assumptions, and valuation paradigms may yield results outside the range projected in our primary analysis, we believe based on the magnitude of the difference between the estimated benefits and costs that it is unlikely that eliminating uncertainties or adopting reasonable alternative assumptions would change the fundamental conclusion of this study: the Clean Air Act Amendments' total benefits to society exceed its costs.

The uncertainties in the primary estimates and the controversies which persist regarding model choices and valuation paradigms nonetheless highlight the need for a variety of new and continued research efforts. Based on the findings of this study, the highest priority research needs are:

- Improved emissions inventories and inventory management systems
- A more geographically comprehensive air quality monitoring network, particularly for fine particles and hazardous air pollutants
- Use of integrated air quality modeling tools based on an open, consistent model architecture
- Development of tools and data to assess the significance of wetland, aquatic, and terrestrial ecosystem changes associated with air pollution
- Increased basic and targeted research on the health effects of air pollution, especially particulate matter
- Continued development of economic valuation methods and data, particularly valuation of changes in risks of premature mortality associated with air pollution

Properly directed and funded, such research would improve the results of future analyses of the benefits and costs of the Clean Air Act.

Review Process

The CAA requires EPA to consult with an outside panel of experts during the development and interpretation of the 812 studies. This panel of experts was organized in 1991 under the auspices of EPA's Science Advisory Board (SAB) as the Advisory Council on Clean Air Act Compliance Analysis (hereafter, the Council). Organizing the review committee under the SAB ensured that highly qualified experts would review the section 812 studies in an objective, rigorous, and publicly open manner consistent with the requirements and procedures of the Federal Advisory Committee Act (FACA). Council review of the present study began in 1993 with a review of the analytical design plan. Since the initial June 1993 meeting, the Council has met many times to review proposed data, proposed methodologies, and interim results. While the full Council retains overall review responsibility for the section 812 studies, some specific issues concerning physical effects and air quality modeling were referred to subcommittees comprised of both Council members and members of other SAB committees. The Council's Health and Ecological Effects Subcommittee (HEES) met several times and provided its own review findings to the full Council. Similarly, the Council's Air Quality Modeling Subcommittee (AQMS) held in-person and teleconference meetings to review methodology proposals and modeling results and conveyed its review recommendations to the parent committee.

An interagency review was conducted, during which a number of analytical issues were discussed. Conducting a benefit/cost analysis of a major statute such as the Clean Air Act requires scores of methodological decisions. Many of these issues are the subject of continuing discussion within the economic and policy analysis communities and within the Administration. Key issues include the treatment of uncertainty in the relationship between particulate matter exposure and mortality; the valuation of premature mortality; the treatment of tax interaction effects; the assessment of stratospheric ozone recovery; and the treatment of ecological and welfare effects. These issues could not be resolved within the constraints of this review. Thus, this report reflects the findings of the EPA and not necessarily other agencies of the Administration.

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Appendix A: Emissions Analysis

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Acronyms and Abbreviations

μEq	microequivalents
μg	microgram
ACT	average cost per ton
AGSIM	AGricultural SImulation Model
AIC	Akaike information criterion
AIRS	Aerometric Information Retrieval System
ANC	acid neutralizing capacity
ANOVA	analysis of variance
AOD	airway obstructive disease
AP-42	EPA's Compilation of Air Pollution Emission Factors
ATDM	aerosol and toxics deposition module
AQM	air quality modeling
AQMS	Air Quality Modeling Subcommittee
ATLAS	Aggregate Timber Land Assessment System
b_{ext}	light extinction coefficient
BAAQMD	Bay Area Air Quality Management District
BACT	best available control technology
BAF	bioaccumulation factor
BARCT	best available retrofit control technology
BCF	bioconcentration factor
BEA	Bureau of Economic Analysis
BID	background information document
BIES	Biogenic Emissions Inventory System
BLS	Bureau of Labor Statistics
BMP	best management practice
BNR	biological nutrient removal
BS	black smoke
C-R	concentration-response
CAA	Clean Air Act
CAAA	Clean Air Act Amendments
CAPI	Clean Air Power Initiative
CAPMS	Criteria Air Pollutant Modeling System
CARB	California Air Resources Board
CASAC	Clean Air Science Advisory Board
CASTNet	Clean Air Act Status and Trends Network
CB	chronic bronchitis
CEM	continuous emissions monitoring
CES	constant elasticity of substitution
CFC	chlorofluorocarbon
CFFP	Clean Fuel Fleet Program
CGE	computable general equilibrium
CI	compression ignition
CO	carbon monoxide
COH	coefficient of haze
COI	cost of illness
COPD	chronic obstructive pulmonary disease
CRC	capital recovery cost
CRF	capital recovery factor
CTG	control technique guideline
CV	contingent valuation
dbh	diameter at breast height
DDT	dichlorodiphenyl-trichloroethane
DOE	Department of Energy
dV	deciview
E-GAS	Economic Growth Analysis System
EC	elemental carbon
EGU	electrical generating unit
EMFAC	emission factors model
ER	emergency room
EPA	Environmental Protection Agency
EPS	Emissions Processing System
ERCAM	Emission Reduction and Cost Analysis Model
ERL	Environmental Research Laboratory
FACA	Federal Advisory Committee Act
FAPRI	Food and Agricultural Policy Research Institute
FCM	Fuel Consumption Model
FDA	Food and Drug Administration
FEV_1	forced expiratory volume in one second

FGD	flue gas desulfurization
FHWA	Federal Highway Administration
FMVCP	Federal Motor Vehicle Control Program
FORCARB	forest carbon model
FORTRAN	formula translation
FR	Federal Register
GCVTC	Grand Canyon Visibility Transport Commission
GDP	gross domestic product
GIRAS	Geographic Information Retrieval Analysis System
GIS	geographic information system
GNP	gross national product
GSP	gross state product
H+	hydrogen ions
ha	hectare
HAP	hazardous air pollutant
HARVCARB	harvested carbon model
HBFC	hydrobromofluorocarbons
HC	hydrocarbon
HCFC	hydrochlorofluorocarbon
HDDV	heavy-duty diesel vehicle
HDGV	heavy-duty gasoline vehicle
HDV	heavy-duty vehicle
HEES	Health and Ecological Effects Subcommittee
Hg	mercury
HIV-1	human immunodeficiency virus type one
HNO_3	nitric acid
HPMS	Highway Performance Monitoring System
HS_2O_4	sulfuric acid
I/M	inspection and maintenance
ICI	industrial/commercial/institutional
ICD	International Classification of Disease
ID	identification code
IMPROVE	Interagency Monitoring of PROtected Environments
IPM	Integrated Planning Model
kg	kilogram
km	kilometer
kWh	kilowatt hour
LAER	lowest achievable emission rate
lb	pound
LDAR	leak detection and repair
LDDT	light-duty diesel truck
LDDV	light-duty diesel vehicle
LDGT	light-duty gasoline truck
LDGV	light-duty gasoline vehicle
LEV	low emission vehicle
LRS	lower respiratory symptom
LTO	landing and takeoff operations
m	meter
m^3	cubic meter
MACT	maximum achievable control technology
MAG	Maricopa Association of Governments
MAGIC	Model of Acidification of Groundwater in Catchments
MC	motorcycle
MCF	methyl chloroform
MDL	method detection limit
MM4	mesoscale model four
MMBtu	million British thermal units
MRAD	minor restricted activity day
Models-3	Third Generation Air Pollution Modeling System
MOU	memorandum of understanding
MOBILE	mobile source emission factor model
MPO	metropolitan planning organization
MWC	municipal waste combustor
MWI	medical waste incinerator
N	nitrogen
NAA	nonattainment area
NAAQS	National Ambient Air Quality Standards
NAPAP	National Acid Precipitation Assessment Program
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCLAN	National Crop Loss Assessment Network
NE	northeast
NEMS	National Energy Modeling System
NERC	North American Electric Reliability Council
NESHAP	National Emission Standards for Hazardous Air Pollutants

NET	National Emission Trend
NH_3	ammonia
NHANES	National Health and Nutrition Examination
NIH	National Institutes of Health
NMOC	non-methane organic compound
NO	nitrogen oxide
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
NP	national park
NPI	National Particulates Inventory
NPP	net primary productivity
NPV	net present value
NSPS	new source performance standard
NSR	new source review
NSWS	National Surface Waters Survey
NYSDEC	New York Department of Environmental Conservation
O_3	ozone
O&M	operation and maintenance
OBD	onboard diagnostic
OC	organic carbon
ODS	ozone-depleting substance
OMB	Office of Management and Budget
OMS	Office of Mobile Sources
OPPE	Office of Policy, Planning and Evaluation
ORIS	Office of the Regulatory Information System
OSD	ozone season daily
OTAG	Ozone Transport Assessment Group
OTC	Ozone Transport Commission
OTR	Ozone Transport Region
P-i-G	plume-in-grid
PAN	peroxyacetyl nitrate
Pb	lead
PCB	polychlorinated biphenyl
PCDD	polychlorinated dibenzo-p-dioxin
PCDF	polychlorinated dibenzofurans
PCE	perchloroethylene
pH	logarithm of the reciprocal of hydrogen ion concentration, a measure of acidity
PM	particulate matter (both PM_{10} and $PM_{2.5}$)
PM_{10}	particulate matter less than or equal to 10 microns in diameter
$PM_{2.5}$	particulate matter less than or equal to 2.5 microns in diameter
PnET	Net Photosynthesis and Evapo-Transpiration model
POC	parameter occurrence code
POTW	publically owned treatment works
ppb	parts per billion
ppm	parts per million
PRYL	percentage relative yield loss
PRZM	Pesticide Root Zone Model
PSU	Pennsylvania State University
QALY	quality adjusted life years
R&D	research and development
RACT	reasonable available control technology
RAD	restricted activity day
RADM	Regional Acid Deposition Model
RELMAP	Regional Lagrangian Model of Air Pollution
REMSAD	Regulatory Modeling System for Aerosols and Acid Deposition
RE	rule effectiveness
RFG	reformulated gasoline
RHC	reactive hydrocarbon
RIA	regulatory impact analysis
RFP	reasonable further progress
RO_2	peroxy radical
ROP	rate of progress
RPM	Regional Particulate Model
RUM	Random Utility Model
RVP	Reid vapor pressure
S	sulfur
SAB	Science Advisory Board
SAS	Statistical Analysis Software
SAV	submerged aquatic vegetation
SCAQMD	South Coast Air Quality Management District
SCAQS	South Coast Air Quality Study
SCC	Source Classification Code
SCR	selective catalytic reduction
SEDS	State Energy Data Systems
SI	spark ignition
SIC	Standard Industrial Classification
SIP	State Implementation Plan
SO_2	sulfur dioxide

SOA	secondary organic aerosol
SoCAB	South Coast Air Basin
SOCMI	synthetic organic chemical manufacturing industry
SUM06	sum of hourly ozone concentrations at or above 0.06 ppm
TAC	total annualized costs
TAF	temporal allocation factors
TAMM	Timber Assessment Market Model
TBRP	Tampa Bay Estuary Program
TCDD	tetrachlorodibenzo-p-dioxin
TEQ	toxic equivalency
TLEV	transitional low emission vehicle
tpd	tons per day
TREGRO	tree growth model
TSDF	treatment, storage, and disposal facility
TSP	total suspended particulates
UAM	Urban Airshed Model
URS	upper respiratory symptoms
USDA	United States Department of Agriculture
ULEV	ultra-low emission vehicle
USGS	United States Geological Survey
UV	ultraviolet
VMT	vehicle miles traveled
VNA	Voronoi neighbor averaging
VOC	volatile organic compound
VR	visual range
VSL	value of statistical life
VSLY	value of statistical life year
WEFA	Wharton Economic Forecasting Associates
WHO	World Health Organization
WLD	work-loss days
WTA	willingness-to-accept
WTP	willingness-to-pay
XO_2	halogenated peroxy radical
yr	year
ZEV	zero emission vehicle

Acknowledgments

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Science Advisory Board review of this report is supervised by Donald G. Barnes, Director of the SAB Staff. The Designated Federal Official for the SAB reviews is Angela Nugent. Other SAB staff who assisted in the coordination of SAB reviews include Jack Fowle, Robert Flaak, and Jack Kooyoomjian. Diana Pozun provided administrative support to the SAB.

The SAB Council is chaired by Maureen Cropper of the World Bank. SAB Council members serving during the final review of this report include A. Myrick Freeman of Bowdoin College, Gardner Brown, Jr. of the University of Washington, Paul Lioy of the Robert Wood Johnson School of Medicine, Paulette Middleton of the RAND Center for Environmental Sciences and Policy, Donald Fullerton of the University of Texas – Austin, Lawrence Goulder of Stanford University, Jane Hall of California State University – Fullerton, Charles Kolstad of the University of California at Santa Barbara, and Lester Lave of Carnegie-Mellon University. Alan Krupnick of Resources for the Future served as a Consultant to the Council. In addition, several members of the SAB Council whose terms expired during the development of the study provided valuable advice and ideas in the early stages of project design and implementation. These former members include Richard Schmalensee of MIT, William Nordhaus of Yale University, Paul Portney of Resources for the Future, Kip Viscusi of Harvard University, Ronald Cummings of Georgia State University, Thomas Tietenberg of Colby College, Wallace Oates of the University of Maryland, Wayne Kachel of MELE Associates, Robert Mendelsohn of Yale University, and Daniel Dudek of the Environmental Defense Fund. William Smith, a liaison to the Council from the SAB Environmental Processes and Effects Committee also provided valuable advice regarding the ecological assessment.

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The second technical subcommittee, the Air Quality Modeling Subcommittee is chaired by Paulette Middleton. Members serving during the final review of this report include Philip Hopke of Clarkson University, James H. Price, Jr. of the Texas Natural Resource Conservation Commission, Harvey Jeffries of the University of North Carolina – Chapel Hill, Timothy Larson, and Peter Mueller of the Electric Power Research Institute. A former member who helped guide the analysis in its early stages was George T. Wolff.

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Introduction

Chapter 1

Background and Purpose

Section 812 of the 1990 Clean Air Act Amendments requires the EPA to develop periodic Reports to Congress that estimate the benefits and costs of the Clean Air Act (CAA). The first report EPA created under this authority, *The Benefits and Costs of the Clean Air Act: 1970 to 1990*, was published and conveyed to Congress in October 1997. This retrospective analysis comprehensively assessed benefits and costs of requirements of the 1970 Clean Air Act and the 1977 Amendments, up to the passage of the Clean Air Act Amendments of 1990. The results of the retrospective analysis showed that the nation's investment in clean air was more than justified by the substantial benefits that were gained in the form of increased health, environmental quality, and productivity. The aggregate benefits of the CAA during the 1970 to 1990 period exceeded costs by a factor of 10 to 100 times.

Before the retrospective analysis was complete, we began the process of assessing the prospective benefits and costs of the Clean Air Act Amendments (CAAA), covering the period 1990 to 2010. This report, the first of a series that we plan to produce every two years, is the result of our prospective analysis of the 1990 Amendments.

Similar to the retrospective analysis, this document has one primary and several secondary objectives. The main goal is to provide Congress and the public with comprehensive, up-to-date information on the CAAA's social costs and benefits, including health, welfare, and ecological benefits. Data and methods derived from the retrospective analysis have already been used to assist policy-makers in refining clean air regulations over the last two years, and we hope the information continues to prove useful to Congress during future Clean Air Act reauthorizations. Beyond the statutory goals of section 812, EPA also intends to use the results of this study to help support decisions on future investments in air pollution research. In addition, lessons learned in conducting this first prospective will help better target efforts to improve the accuracy and usefulness of future prospective analyses.

Relationship of This Report to Other Regulatory Analyses

The Clean Air Act Amendments of 1990 augment the significant progress made in improving the nation's air quality through the original Clean Air Act of 1970 and its 1977 amendments. The amendments built off the existing structure of the original Clean Air Act, but went beyond those requirements to tighten and clarify implementation goals and timing, increase the stringency of some federal requirements, revamp the hazardous air pollutant regulatory program, refine and streamline permitting requirements, and introduce new programs for the control of acid rain and stratospheric ozone depleters. Because the 1990 Amendments represent an additional improvement to the nation's existing clean air program, the analysis summarized in this report was designed to estimate the costs and benefits of the 1990 CAAA incremental to those costs and benefits assessed in the retrospective analysis. In economic terminology, this report addresses the marginal costs and benefits of the 1990 CAAA. Our intent is that this report and its predecessor, the retrospective analysis, together provide a comprehensive assessment of current and expected future clean air regulatory programs and their costs and benefits.

Because of the time and resources necessary to conduct this type of comprehensive prospective assessment, however, and the ongoing refinements in Clean Air Act regulatory programs, the estimates presented in this report do not reflect some recent major developments in EPA's clean air program. The prospective analysis, for example, does not capture the benefits and costs of EPA's recent revision of the particulate matter and ozone National Ambient Air Quality Standards (NAAQS), the recently proposed Tier II tailpipe standards, or the recently finalized regional haze standards. Neither costs nor benefits of those actions are reflected in the estimates presented here. In most cases, Regulatory Impact Analyses (RIAs) for those actions did incorporate the section 812 prospective Post-CAAA scenario as their starting point, or baseline, from which the actions were assessed, and in most respects the RIAs used a methodology consistent with that used here.[1] As a result, cost and benefit estimates presented in those RIAs can be considered incremental to the primary estimates presented in this document.

In addition to omitting these actions from the assessment, this first prospective analysis required locking in a set of emissions reductions to be used in subsequent analyses at a relatively early date (late 1996), and as a result we were compelled to forecast the implementation outcome of several pending programs. The most important of these was the then-ongoing Ozone Transport Assessment Group (OTAG) recommendations for achieving regional-scale reductions of emissions of ground-level ozone precursors. The NOx control program incorporated in the Post-CAAA scenario may not reflect the NOx controls that are actually implemented in a regional ozone transport rule. We acknowledge and discuss these types of discrepancies and their impact on the outcome of our analysis in the document.

Finally, despite our efforts to comprehensively evaluate the costs and benefits of all provisions of the Clean Air Act and its Amendments, there remain a few categories of effects that are not addressed by either the retrospective or prospective analyses. For example, this first prospective analysis does not assess the effect of CAAA provisions on lead exposures, primarily because the 1990 Amendments do not include major new provisions for the control of lead emissions. The vast majority of lead emissions sources present in 1970 were addressed by programs initiated under the original Clean Air Act and the 1977 Amendments; evaluation of the costs and health benefits of these programs were important elements of the retrospective analysis. In the retrospective, however, we were unable to quantify the potentially substantial ecological benefits of controls on lead emissions. While this first prospective analysis reflects a significantly greater investment in quantifying ecological effects, for the reason stated above we did not assess the ecological effects of lead in this analysis either. As a result, the ecological effects of this persistent pollutant, past emissions of which may continue to be released from soils for many years, are not captured by either the retrospective or prospective analyses. In addition, lead previously deposited to soils may be re-entrained in the air as road dust, dust plumes from construction excavations, and other particulate matter emission processes subject to 1990 CAAA controls. Reductions in this re-entrainment of, and potential exposure to, pre-1990 emitted lead due to post-1990 control programs, however, are not reflected in either the section 812 retrospective (1970 to 1990) or prospective (1990 to 2010) benefit analyses.

Requirements of the 1990 Clean Air Act Amendments

The first prospective analysis, despite the limitations discussed above, presents a comprehensive estimate of costs and benefits of all titles of the 1990 Clean Air Act Amendments. The 1990 Amendments consist of the following eleven titles:

- **Title I.** Establishes a detailed and graduated program for the attainment and maintenance of the National Ambient Air Quality Standards.
- **Title II.** Regulates mobile sources and establishes requirements for reformulated gasoline and clean fuel vehicles.
- **Title III.** Expands and modifies regulations of hazardous air pollutant emissions; and establishes a list of 189 hazardous air pollutants to be regulated.

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[1] There are minor differences in the assumptions used to construct the Post- CAAA scenario for this analysis and the baseline used in the PM and ozone NAAQS RIA. For example, the RIA baseline incorporates the effects of 7- and 10-year MACT rules that are not reflected here, because of the timing of the two analyses, and the RIA used a 95 percent rule-effectiveness assumption. In most respects, however, the analyses are compatible.

- **Title IV.** Establishes control programs for reducing acid rain precursors.

- **Title V.** Requires a new permitting system for primary sources of air pollution.

- **Title VI.** Limits emissions of chemicals that deplete stratospheric ozone.

- **Title VII.** Presents new provisions for enforcement.

- **Titles VIII through XI.** Establishes miscellaneous provisions for issues such as disadvantaged business concerns, research, training, new regulation of outer continental shelf sources, and assistance for people who lose their jobs as a result of the Clean Air Act Amendments.

As part of the requirements under Title VIII, section 812 of the Clean Air Act Amendments of 1990 requires the EPA to analyze the costs and benefits to human health and the environment that are attributable to the Clean Air Act. In addition, section 812 directs EPA to measure the effects of this statute on economic growth, employment, productivity, cost of living, and the overall economy of the United States.

Analytical Design and Review

Target Variable

The prospective analysis compares the overall health, welfare, ecological and economic benefits of the 1990 Clean Air Act Amendment programs to the costs of these programs. By examining the overall effects of the Clean Air Act, this analysis complements the Regulatory Impact Analyses (RIAs) developed by EPA over the years to evaluate individual regulations. Resources were used more efficiently by recognizing that these RIAs, and other EPA analyses, provide complete information about the costs and benefits of specific rules. Within this analysis, costs can be reliably attributed to individual programs, but the broad-scale approach adopted in the prospective study precludes reliable re-estimation of the benefits of individual standards or programs. Similar to the retrospective benefits analysis, this study calculates the change in incidences of adverse effects implied by changes in ambient concentrations of air pollutants. However, pollutant emissions reductions achieved contribute to changes in ambient concentrations of those, or secondarily formed, pollutants in ways that are highly complex, interactive, and often nonlinear. Therefore, benefits cannot be reliably matched to provision-specific changes in emissions or costs.

Focusing on the broader target variables of overall costs and overall benefits of the Clean Air Act, the EPA Project Team adopted an approach based on construction and comparison of two distinct scenarios: a “Pre-CAAA” and a “Post-CAAA” scenario. The Pre-CAAA scenario essentially freezes federal, state, and local air pollution controls at the levels of stringency and effectiveness which prevailed in 1990. The Post-CAAA scenario assumes that all federal, state, and local rules promulgated pursuant to, or in support of, the 1990 CAAA were implemented. This analysis then estimates the differences between the economic and environmental outcomes associated with these two scenarios. For more information on the scenarios and their relationship to historical trends, see Chapter 2 and Appendix A of this document.

Key Assumptions

Similar to the retrospective analysis, we made two key assumptions during the scenario design process to avoid miring the analytical process in endless speculation. First, as stated above, we froze air pollution controls at 1990 levels throughout the Pre-CAAA scenario. Second, we assumed that the geographic distributions of population and economic activity remain the same between the two scenarios, although these distributions do change over time under both scenarios to reflect expected patterns of high and low population and economic growth across the country.

The first assumption is an obvious simplification. In the absence of the 1990 CAAA, one would expect to see some air pollution abatement activity, either voluntary or due to state or local regulation. It is conceivable that state and local regulation would have required air pollution abatement equal to –or even greater than– that required by the 1990 CAAA;

particularly since some states, most notably California, have in the past done so. If one were to assume that state and local regulations would have been equivalent to 1990 CAAA standards, then a cost-benefit analysis of the 1990 CAAA would be a meaningless exercise since both costs and benefits would equal zero. Any attempt to predict how states' and localities' regulations would have differed from the 1990 CAAA would be too speculative to support the credibility of the ensuing analysis. Instead, the Pre-CAAA scenario has been structured to reflect the assumption that states and localities would not have invested further in air pollution control programs after 1990 in the absence of the federal CAAA. Thus, this analysis accounts for all costs and benefits of air pollution control from 1990 to 2010 and does not speculate about the fraction of costs and benefits attributable exclusively to the federal CAAA. Nevertheless, it is important to note that state and local governments and private initiatives are responsible for a significant portion of these total costs and total benefits. In the end, the benefits of air pollution controls result from partnerships among all levels of government and with the active participation and cooperation of private entities and individuals.

The second assumption concerns changing demographic patterns in response to air pollution. In the hypothetical Pre-CAAA scenario, air quality is worse than the actual 1990 conditions and the projected air quality in the Post-CAAA scenario. It is possible that under the Pre-CAAA scenario more people, relative to the Post-CAAA case, would move away from the most heavily polluted areas. Rather than speculate on the scale of population movement, the analysis assumes no differences in demographic patterns between the two scenarios. Similarly, the analysis assumes no differences between the two scenarios with respect to the spatial pattern of economic activity.

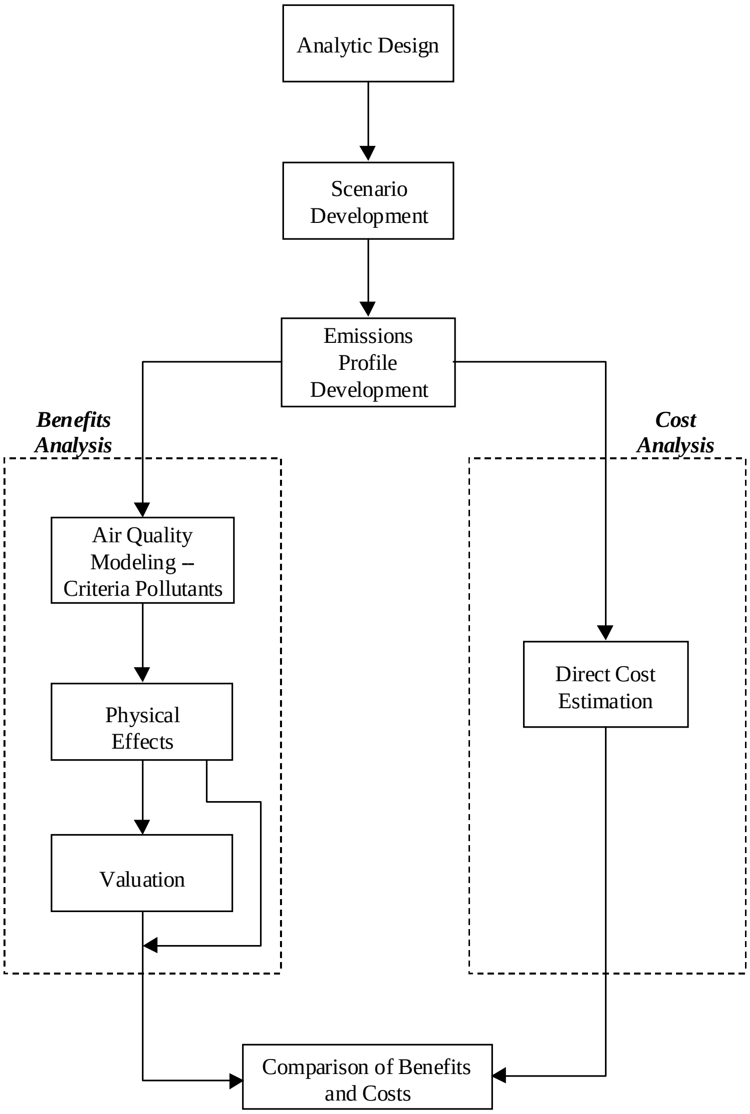
Analytic Sequence

The analysis comprises a sequence of six basic steps, summarized below and described in detail later in this report. These six steps, listed in order of completion, are:

(1) emissions modeling
(2) direct cost estimation
(3) air quality modeling
(4) health and environmental effects estimation
(5) economic valuation
(6) results aggregation and uncertainty characterization

Figure 1-1 summarizes the analytical sequence used to develop the prospective results; we describe the analytic process in greater detail below.

Figure 1-1
Analytic Sequence for First Section 812 Prospective Analysis



The first step of the analysis is the estimation of the effect of the 1990 CAAA on emissions sources. We generated emissions estimates through a three step process: (1) construction of an emissions inventory for the base year (1990); (2) projection of emissions for the Pre-CAAA case for two target years, 2000 and 2010, assuming a freeze on emissions control regulation at 1990 levels and continued economic progress, consistent with sector-specific Bureau of Economic Analysis economic activity projections; and (3) construction of Post-CAAA estimates for the same two target years, using the same set of economic activity projections used in the Pre-CAAA case but with regulatory stringency, scope, and timing consistent with EPA's CAAA implementation plan (as of late 1996). The analysis reflects application of utility and other sector-specific emissions models developed and used in various offices of EPA's Office of Air and Radiation. These emissions models provide estimates of emissions of six criteria air pollutants[2] from each of several key emitting sectors. We provide more details in Chapter 2 and Appendix A.

The emissions modeling step is a critical component of the analysis, because it establishes consistency between the subsequent cost and benefit estimates that we develop. Estimates of direct compliance costs to achieve the emissions reductions estimated in the first step are generated as either an integral or subsequent output from the emissions estimation models, depending on the model used. For example, the Integrated Planning Model used to estimate emissions and compliance costs for the utility sector develops an optimal allocation of reductions of sulfur and nitrogen oxides taking into account the regulatory flexibility inherent in the Title IV trading schemes for emissions allocations. In a few cases, for example the Title V permitting requirements, we estimate public and private costs incurred to implement the regulatory requirements through analysis of the relevant RIAs conducted to support promulgation of the rules.

Emissions estimates also form the first step in estimating benefits. After the emissions inventories are developed, they are translated into estimates of air quality conditions under each scenario. Given the complexity, data requirements, and operating costs of state-of-the-art air quality models, and the project's resource constraints, the EPA Project Team adopts simplified, linear scaling approaches for some gaseous pollutants. However, for particulate matter, ozone, and other air quality conditions that involve substantial non-linear formation processes and/or long-range atmospheric transport and transformation, the EPA Project Team invests the time and resources needed to use more sophisticated modeling systems. For example, we exercise EPA's Regional Acid Deposition Model/Regional Particulate Model (RADM/RPM) to estimate secondarily formed particulate matter in the eastern U.S.

Up to this point of the analysis, modeled conditions and outcomes establish the Pre-CAAA and Post-CAAA scenarios. However, at the air quality modeling step, the analysis returns to a foundation based on actual historical conditions and data. Specifically, actual 1990 historical air quality monitoring data are used to define the baseline conditions from which the Pre-CAAA and Post-CAAA scenario air quality projections are constructed. We derive air quality conditions under the Pre-CAAA scenario by scaling the historical data adopted for the base-year (1990) by the ratio of the modeled Pre-CAAA and base-year air quality. We use the same approach to estimate future-year air quality for the Post-CAAA scenario. This method takes advantage of the richness of the monitoring data on air quality, provides a realistic grounding for the benefit measures, and yet retains analytical consistency by using the same modeling process for both scenarios. The outputs of this step of the analysis are profiles for each pollutant characterizing air quality conditions at each monitoring site in the lower 48 states.

The Pre-CAAA and Post-CAAA scenario air quality profiles serve as inputs to a modeling system that translates air quality to physical outcomes (e.g., mortality, emergency room visits, or crop yield

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[2] The six pollutants are particulate matter (separate estimates for each of PM$_{10}$ and PM $_{2.5}$), sulfur dioxide (SO$_2$), nitrogen oxides (NO$_x$), carbon monoxide (CO), volatile organic compounds (VOCs), and ammonia (NH$_3$). One of the CAA criteria pollutants, ozone (O$_3$), is formed in the atmosphere through the interaction of sunlight and ozone precursor pollutants such as NO$_x$ and VOCs. Ammonia is not a criteria pollutant, but is an important input to the air quality modeling step because it affects secondary particulate formation. The sixth criteria pollutant, lead (Pb), is not included in this analysis since airborne emissions of lead were virtually eliminated by pre-1990 Clean Air Act programs.

losses) through the use of concentration-response functions. Scientific literature on the health and ecological effects of air pollutants provides the source of these concentration-response functions. At this point, we derive estimates of the differences between the two scenarios in terms of incidence rates for a broad range of human health and other effects of air pollution by year, by pollutant, and by geographic area.

In the next step, we use economic valuation models or coefficients to estimate the economic value of the reduction in incidence of those adverse effects amenable to monetization. For example, a distribution of unit values derived from the economic literature provides estimates of the value of reductions in mortality risk. In addition, we compile and present benefits that cannot be expressed in economic terms. In some cases, we calculate quantitative estimates of scenario differences in the incidence of a nonmonetized effect. In many cases, available data and techniques are insufficient to support anything more than a qualitative characterization of the change in effects.

Next, we compare costs and monetized benefits to provide our primary estimate of the net economic benefits of the 1990 CAAA and associated programs, and a range of estimates around that primary estimate reflecting quantified uncertainties associated with the physical effects and economic valuation steps. The monetized benefits used in the net benefit calculations reflect only a portion of the total benefits due to limitations in analytical resources, available data and models, and the state of the science. For example, in many cases we are unable to quantify or monetize the potentially large benefits of air pollution controls that result from protection of the health, structure, and function of ecosystems. In addition, although available scientific studies demonstrate clear links between air quality changes and changes in many human health effects, the available studies do not always provide the data needed to quantify and/or monetize some of these effects.

Finally, we present a limited set of alternative benefit estimates which reflect methods, models, or assumptions that differ from those we used to derive the primary net benefit estimate. We also quantify some of the uncertainties surrounding these alternative estimates. In addition, beyond those variables for which alternative results are estimated, we conduct sensitivity analyses for a number of variables that may influence the primary net benefit estimate. The primary estimate and the range around this estimate, however, reflect our current interpretation of the available literature; our judgments regarding the best available data, models, and modeling methodologies; and the assumptions we consider most appropriate to adopt in the face of important uncertainties.

In addition, throughout the report at the end of the chapter we summarize the major sources of uncertainty for each analytic step. Although the impact of many of these uncertainties cannot be quantified, we qualitatively characterize the magnitude of effect on our net benefit results by assigning one of two classifications to each source of uncertainty: *potentially major* factors could, in our estimation, have effects of greater than five percent of the total net benefits; and *probably minor* factors likely have effects less than five percent of total net benefits.

Review Process

The CAA requires EPA to consult with an outside panel of experts during the development and interpretation of the 812 studies. This panel of experts was organized in 1991 under the auspices of EPA's Science Advisory Board (SAB) as the Advisory Council on Clean Air Act Compliance Analysis (hereafter, the Council). Organizing the review committee under the SAB ensured that highly qualified experts would review the section 812 studies in an objective, rigorous, and publicly open manner consistent with the requirements and procedures of the Federal Advisory Committee Act (FACA). Council review of the present study began in 1993 with a review of the analytical design plan. Since the initial June 1993 meeting, the Council has met many times to review proposed data, proposed methodologies, and interim results. While the full Council retains overall review responsibility for the section 812 studies, some specific issues concerning physical effects and air quality modeling were referred to subcommittees comprised of both Council members and members of other SAB committees. The Council's Health and Ecological Effects Subcommittee (HEES) met several times and provided its own review findings to the full Council. Similarly, the Council's Air Quality Modeling Subcommittee (AQMS) held in-person and teleconference meetings to review methodology proposals and modeling results and conveyed its review recommendations to the parent committee.

An interagency review was conducted, during which a number of analytical issues were discussed. Conducting a benefit/cost analysis of a major statute such as the Clean Air Act requires scores of methodological decisions. Many of these issues are the subject of continuing discussion within the economic and policy analysis communities and within the Administration. Key issues include the treatment of uncertainty in the relationship between particulate matter exposure and mortality; the valuation of premature mortality; the treatment of tax interaction effects; the assessment of stratospheric ozone recovery; and the treatment of ecological and welfare effects. These issues could not be resolved within the constraints of this review. Thus, this report reflects the findings of the EPA and not necessarily other agencies of the Administration.

Report Organization

The remainder of the main text of this report summarizes the key methodologies and findings our prospective study.

- Chapter 2 summarizes emissions modeling and key elements of the regulatory scenarios.
- Chapter 3 discusses the direct cost estimation.
- Chapter 4 presents the air quality modeling methodology and sample results.
- Chapter 5 describes the approaches used and principal results obtained through the human health effects estimation process.
- Chapter 6 describes the human health effects economic valuation methodology and results.
- Chapter 7 summarizes the ecological and other welfare effects analyses, including assessments of commercial timber, agriculture, visibility, and other categories of effects.
- Chapter 8 presents the aggregated results of the cost and benefit estimates and describes and evaluates important uncertainties in the results.

Additional details regarding the methodologies and results are presented in the appendices and in the referenced supporting documents.

- Appendix A provides additional detail on the sector-specific emissions modeling effort.
- Appendix B covers the direct costs.
- Appendix C provides details of the air quality models used and results obtained.
- Appendix D presents the human health effects estimation methodology and results.
- Appendix E describes the ecological benefits estimation methods and results.
- Appendix F presents the agricultural benefits estimation methodology and results.
- Appendix G provides details of the stratospheric ozone analysis.
- Appendix H describes the methods and assumptions used to value quantified effects of the CAA in economic terms.
- Appendix I describes areas of research which may increase comprehensiveness and/or reduce uncertainties in effect estimates for future assessments.

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Emissions

Chapter 2

Estimation of pollutant emissions, a key component of this prospective analysis, serves as the starting point for subsequent benefit and cost estimates. We focused the emissions analysis on six major pollutants: volatile organic compounds (VOCs), nitrogen oxides (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO), particulate matter with an aerodynamic diameter of 10 microns or less (PM_{10}), and fine particulate matter ($PM_{2.5}$).[1] For each of these pollutants we projected 1990 emissions to the years 2000 and 2010 under two different scenarios: a) the *Pre-CAAA* scenario which assumes no additional control requirements would be implemented beyond those in place when the 1990 Amendments were passed; and b) the *Post-CAAA* scenario which incorporates the effects of controls authorized by the 1990 Amendments. We compare the emissions estimates under each of these scenarios to forecast the effect of the CAAA requirements on future emissions.

This chapter consists of four sections. The first section provides an overview of our approach for developing the Pre- and Post-CAAA control scenarios and projecting emissions from 1990 levels to 2000 and 2010. The second section summarizes our emissions projections for the years 2000 and 2010 and presents our estimates of changes in future emissions resulting from the implementation of the 1990 Amendments. The third section compares these results with other estimates that are based upon more recent emissions data. Finally, we conclude this chapter with a summary of the key uncertainties associated with estimating emissions.

Overview Of Approach

We projected emissions for five major source categories: industrial point sources, utilities, nonroad engines/vehicles, motor vehicles, and area sources (see Table 2-1).[2] The basic method involves estimating emissions in the 1990 base-year, adjusting the base-year emissions to reflect projected growth in the level of pollution-generating activity by 2000 and 2010 in the absence of additional CAAA requirements, and modifying these projections to reflect future-year control assumptions. The resulting estimates depend largely upon three factors: the method for selecting the base-year inventory, the indicators used to forecast growth and the effectiveness of future controls, and the specific regulatory programs incorporated in the Pre- and Post-CAAA scenarios.

We constructed the base-year inventory using 1990 emissions levels. For all of the air pollutants examined in this analysis except particulate matter, we selected emissions levels from Version 3 of the National Particulates Inventory (NPI) to serve as the baseline. This inventory consists of emissions data compiled primarily by the National Acid Precipitation Assessment Program (NAPAP), EPA's Office of Mobile Sources (OMS), and the Federal Highway Administration (FHWA). For both $PM_{2.5}$ and PM_{10}, however, we updated NPI estimates to incorporate changes in the methodology used to calculate fugitive dust emissions. Adoption of this new technique, also used to develop EPA's National Emission Trend

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[1] We also estimated ammonia (NH_3) emissions. NH_3 influences the formation of secondary PM (PM formed as a result of atmospheric chemical processes). We used NH_3 emissions estimates as an input during the air quality modeling phase of the prospective analysis when estimating future-year ambient PM concentrations. However, we did not examine the human health and environmental effects of exposure to NH_3. In addition to NH_3, we also estimated mercury (Hg) emissions. We qualitatively evaluated the effects of Hg emissions on ecological systems, but we did not examine the impact of Hg on human health. We did not estimate the effect of the CAAA on lead (Pb) emissions. By 1990 most major airborne Pb emission sources were already controlled and the CAAA has minimal additional impact on Pb emissions.

[2] We estimated utility and industrial point source emissions at the plant/facility level. We estimated nonroad engine/vehicle, motor vehicle, and area source emissions at the county level.

Table 2-1
Major Emissions Source Categories

Source Category	Examples
Industrial Point Sources	boilers, cement kilns, process heaters, turbines
Utilities	electricity producing utilities
Nonroad Engines/Vehicles	aircraft, construction equipment, lawn and garden equipment, locomotives, marine engines
Motor Vehicles	buses, cars, trucks (sources that usually operate on roads and highways)
Area Sources	agricultural tilling, dry cleaners, open burning, wildfires

(NET) $PM_{2.5}$ and PM_{10} inventory, leads to lower estimates of fugitive dust emissions and therefore of overall primary PM.[3]

Once we established the base-year inventory, we projected emissions to the years 2000 and 2010, accounting for the influences expected to cause future emissions to differ from 1990 levels. For all but utility sources, we rely on an emissions analysis using the Emissions Reduction and Cost Analysis Model (ERCAM) which incorporates the effects of the level of pollution-generating activity and the stringency and success of regulations designed to protect air quality. In this analysis, we view changes in economic growth as an important indicator of future activity levels and thus, future emissions. We used 1995 Bureau of Economic Analysis (BEA) Gross State Product (GSP) projections to forecast the growth of emissions from industrial point sources. We relied on BEA GSP projections as well as data on BEA predicted changes in population to estimate future emissions from nonroad and area sources.[4] We used BEA population growth as an indicator of the increase in nonroad emissions from recreational marine vessels, recreational vehicles, and lawn/garden equipment as well as an indicator of the increase in area source solvent emissions (e.g., VOC emissions from dry cleaners). For motor vehicle sources, we estimated the growth in activity based primarily on the projected increase in vehicle miles traveled (VMT). We develop future VMT estimates using the EPA MOBILE fuel consumption model.

We estimated the impact of CAAA regulations on industrial point source, nonroad, motor vehicle, and area source emissions based on expected control efficiency and rule effectiveness. Control efficiency represents the percentage reduction in emissions anticipated as a result of the implementation of the CAAA, assuming full compliance and successful operation of all control mechanisms. The rule effectiveness factor accounts for equipment malfunction, non-compliance, and other circumstances that influence the overall effectiveness of air pollution regulations. We selected a rule effectiveness of 80 percent as the standard for this analysis which we applied to stationary source NO_x and VOC controls.[5] Rule effectiveness was not calculated for mobile source controls as an adjustment factor separate from the emissions rates estimated for the various vehicle classes.

To estimate future utility source emissions, we relied on the Integrated Planning Model (IPM). This optimization model forecasts, for the 48 contiguous states and the District of Columbia, emissions from all existing utility power generation units, as well as from independent power producers and other cogeneration facilities that sell wholesale power and are included in the North American Electric Reliability Council (NERC) data base for reliability planning. The model considers future capacity additions by both utilities and independent power producers which might cause an increase in emissions. In addition, the model is capable of producing baseline air

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[3] Primary PM consists of directly emitted particles such as wood smoke and road dust. Secondary PM forms in the atmosphere as a result of atmospheric chemical reactions.

[4] The growth forecast for area source agricultural tilling is based on projections of acres planted, not BEA GSP and population projections.

[5] At the time we selected the general rule effectiveness for use in this analysis, 80 percent was the standard factor applied in air pollution modeling. More recent analyses have used higher rule effectiveness values. If a higher rule effectiveness value had been used in this analysis, emissions reduction estimates would be larger and the estimated benefits associated with air quality improvements would be greater.

emissions forecasts and estimates of air emissions levels under various control options at the national and NERC regional and subregional level. We used IPM to estimate base-year (1990) utility source emissions and to project future-year (2000 and 2010) emissions under both the Pre- and Post-CAAA scenarios.

Using emissions analysis or IPM, we estimated future emissions for each of the five major source categories under both the Pre- and Post-CAAA scenarios. While the selection of the base-year inventory, emission growth factors, and rate of regulatory effectiveness all influence the emissions projections, the difference between Pre- and Post-CAAA estimates is primarily determined by the difference in control assumptions incorporated in the two projection scenarios.

Scenario Development

We developed two contrasting emissions control scenarios, the Pre-CAAA scenario and the Post-CAAA scenario. The Pre-CAAA scenario maintains the air pollution regulatory requirements which existed in 1990 through the 2000 and 2010 analytical period and serves as a baseline against which we measure the changes in emissions projected under the Post-CAAA scenario.[6] This latter scenario assumes the implementation of the 1990 Clean Air Act Amendments and incorporates the influences of the following provisions:

- Title I VOC and NO_x reasonably available control technology (RACT) and reasonable further progress (RFP) requirements for ozone nonattainment areas;
- Title II motor vehicle and nonroad engine/vehicle provisions;
- Title III 2- and 4-year maximum achievable control technology (MACT) standards;
- Title IV SO_2 and NO_x emissions programs for utilities;
- Title V permitting system for primary sources of air pollution; and
- Title VI emissions limits for chemicals that deplete stratospheric ozone.[7]

The Post-CAAA scenario also assumes the implementation of region-wide NO_x controls and a cap-and-trade system designed to reduce emissions during the summer months from large utility and industrial sources in the 37 easternmost states that comprise the Ozone Transport Assessment Group (OTAG) domain.[8] In addition, the Post-CAAA scenario incorporates the effects of a similarly designed trading program for the 11 northeast states that comprise the Ozone Transport Region (OTR). This trading program is consistent with Phase II of the Ozone Transport Commission (OTC) Memorandum of Understanding (MOU).[9] We provide more detailed discussion of both Pre- and Post-CAAA scenario development in Appendix A.

Emissions Estimation Results

The results of the Pre- and Post-CAAA projections indicate that the 1990 Clean Air Act Amendments will likely have a significant effect on future emissions of air pollutants. Table 2-2 displays both base-year (1990) and future-year (2000 and 2010) emissions estimates for the modeled scenarios along with the percent change from Pre- to Post-CAAA VOC, NO_x, SO_2, CO, PM_{10}, and $PM_{2.5}$ projections. A more detailed breakout of 2010 Pre- and Post-CAAA emissions estimates, displaying emissions for each major source category, is contained in Table 2-3. Figures 2-1 through 2-6 show the emissions projections for each of the pollutants examined in this analysis.

Emissions projections for VOC, NO_x, SO_2, and CO, displayed in Figures 2-1 through 2-4, follow

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[6] We also attempted to incorporate in the Pre-CAAA (baseline) scenario the non-CAAA regulations and policies we expect will have a significant effect on emissions between 1990 and 2010. For example, the IPM, which we used to estimate utility emissions, incorporates the effect of the deregulation of railroad rates on SO_2 emissions. IPM accounts for the influence of the future cost of low-sulfur coal prices expected to occur as a result of lower railroad rates. The impact of prescribed burning policies for private and federally owned lands on PM emissions is also incorporated in the Pre-CAAA scenario.

[7] For a more detailed discussion of the CAAA provisions incorporated in the Post-CAAA scenario, see Appendix A.

[8] The NO_x control program incorporated in the Post-CAAA scenario may not reflect the NO_x controls that are actually implemented in a regional ozone transport rule.

[9] The Post-CAAA scenario does not incorporate any influences of the recently revised PM and ozone NAAQS regulations or any impact of the recently proposed Tier II tailpipe standards.

Table 2-2
Summary of National Annual Emissions Projections
(thousand tons)

Pollutant	1990 Base-Year	2000 Pre-CAAA	2000 Post-CAAA	2000 % Change	2010 Pre-CAAA	2010 Post-CAAA	2010 % Change
VOC	22,715	24,410	17,874	-27%	27,559	17,877	-35%
NO_x	22,747	25,021	18,414	-26%	28,172	17,290	-39%
SO_2	22,361	24,008	18,013	-25%	26,216	18,020	-31%
CO	94,385	95,572	80,919	-15%	107,034	81,943	-23%
Primary PM_{10}	28,289	28,768	28,082	-2%	28,993	28,035	-3%
Primary $PM_{2.5}$	7,091	7,353	7,216	-2%	7,742	7,447	-4%

Notes: Totals reflect emissions for the 48 contiguous States, excluding Alaska and Hawaii.
Percent change between Pre-CAAA and Post-CAAA scenarios.

similar patterns. Pre-CAAA estimates indicate emissions of these pollutants would increase, on average, by almost 20 percent from 1990 to 2010. These increases reflect the expectation that anticipated growth in activity levels in the relevant emitting sectors will more than offset reductions achieved by pre-1990 control programs. While we predict relatively steady growth in emissions in the absence of the 1990 Amendments, projections show emissions of these four pollutants would increase at a slightly faster rate over the last ten years of the 20 year projection period.

Post-CAAA estimates of VOC, NO_x, SO_2, and CO emissions for the modeled regulatory scenarios decrease significantly from 1990 to 2000 and then plateau, remaining relatively constant from 2000 to 2010. The initial decrease is triggered by the implementation of the CAAA and the associated controls. After cleaner means of production are adopted, better emissions control technologies are implemented, and other required changes and improvements are made, emissions reduction slows and in some instances stops all together; emissions may even begin to increase. Although the Post-CAAA estimates for each of the above mentioned pollutants show little or no change in the level of emissions from 2000 to 2010, an overall comparison of our Pre- and Post-CAAA projections indicates that during this time period the 1990 Amendments continue to have an increasingly beneficial effect on emission levels.

Comparison of Pre- and Post- CAAA emissions estimates reveals that by 2010, estimated VOC emissions will be 35 percent lower as a result of the implementation of the CAAA than they would have been if no new control requirements, beyond those in place in 1990, were mandated. This sizeable change in emissions attributable to the Amendments is due largely to estimated VOC reductions from motor vehicle and area sources. The 2010 Post-CAAA estimate for these two source categories combined is 8.2 million tons lower than the Pre-CAAA projection, a total which accounts for 84 percent of the predicted difference in VOC emissions estimated under the two scenarios.

Based on the regulatory programs incorporated in the Post-CAAA scenario, we project that NO_x emissions will be reduced by the greatest percentage. Comparison of projections for the year 2010 indicates the Post-CAAA NO_x estimate is 39 percent lower than the Pre-CAAA estimate, representing a decrease in emissions of 10.8 million tons. We project nearly half of this reduction will come from utilities, while the remaining portions will come from cuts in motor vehicle and non-utility point source emissions.

Figure 2-3 shows that by 2010 we anticipate SO_2 levels will be 31 percent lower than they would have been under the Pre-CAAA scenario. We project 96 percent of the 8.2 million ton difference between Pre- and Post-CAAA estimates will result from regulation of utilities, while the remaining reduction comes from motor vehicles.

We estimate 2010 Post-CAAA CO emissions will be 81.9 million tons, 23 percent lower than the Pre-CAAA projection. Much of this reduction we project will be achieved as a result of nonattainment (Title I) and motor vehicle provisions (Title II) of the 1990 Amendments. The more influential programs (in order of importance) are expected to be enhanced vehicle emission inspections, wintertime oxygenated fuel use, and LEV program adoption.

Figures 2-5 and 2-6 indicate that the 1990 Clean Air Act Amendments have more modest effects on primary PM_{10} and $PM_{2.5}$ emissions.[10] For both of these pollutants, Pre-CAAA projections increase at a slow rate from 1990 to 2010. Post-CAAA emissions estimates for primary PM_{10} and $PM_{2.5}$, however, follow different paths. While we estimate implementation of the CAAA will cause primary PM_{10} levels to slowly decrease from 1990 to 2010, Post-CAAA projections indicate primary $PM_{2.5}$ emissions will actually rise despite the influence of the CAAA. Overall, however, emissions of primary PM_{10} and $PM_{2.5}$ both will be approximately four percent lower in 2010 than they would have been without the CAAA.[11]

The significant influence of area source emissions on primary PM emissions levels, combined with the limited regulation of this major source category, explains the limited effect of the CAAA on primary particulate matter emissions. According to data used in this analysis, area sources account for over 90 percent of primary PM_{10} emissions and over 80 percent of primary $PM_{2.5}$ emissions.[12] As a result, even the successful reduction of motor vehicle and nonroad emissions have only a slight impact on overall primary PM_{10} and $PM_{2.5}$ estimates developed for this study.[13] Furthermore, the CAAA's most significant primary PM area source controls target emissions in counties not in compliance with the National Ambient Air Quality Standards (NAAQS).[14] Currently, however, there are fewer than 85 counties in the country that are not in attainment with the national standards. Emissions changes in these areas are capable of having only a minor influence on the overall primary PM level in the United States. Even minor changes in primary PM emissions leading to minor changes in the concentrations of this pollutant, however, are significant. In the subsequent portions of this analysis, sizable benefits are estimated to result from small reductions in PM concentrations in the atmosphere.

The seemingly small impact on direct PM emissions resulting from implementation of the CAAA depicted in Figures 2-5 and 2-6 can be misleading. While these figures illustrate the impact of the 1990 CAAA on primary PM emissions, it is important to remember that ambient PM concentrations are influenced by the presence of both primary and secondary PM. VOCs, NO_x, and SO_2, all pollutants regulated by the CAA, are secondary PM precursors. The reduction in the emissions of these three pollutants also leads to lower overall PM concentrations in the atmosphere. The complete impact of the CAAA on PM thus is not fully captured by Figures 2-5 and 2-6. Additional discussion of the influence of the CAAA on PM and ambient air quality is provided in Chapter 4 and Appendix C.

As part of this prospective analysis we also estimated future-year NH_3 emissions. The 1990 Amendments, however, do not include provisions designed

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[10] EPA projected PM_{10} and $PM_{2.5}$ levels holding natural source emissions of particulate matter constant at 1990 levels. The estimates presented in Figures 2-5 and 2-6 have been adjusted; these estimates represent total PM emissions minus natural source emissions (wind erosion).

[11] Directly emitted PM, such as fugitive dust, is referred to as primary PM. Secondary PM is not directly emitted, but rather forms in the atmosphere. NO_s and SO_2 are two examples of secondary PM precursors.

[12] As discussed on pages 18 and 20 and in Table 2-5, however, some recent data indicate that the composition data used in this analysis may underestimate the contribution from motor vehicle carbonaceous emissions.

[13] The difference between 2010 Pre- and Post-CAAA estimates for PM_{10} and $PM_{2.5}$ motor vehicle emissions is 31 percent and 39 percent respectively. The difference between 2010 Pre- and Post CAAA estimates for PM_{10} and $PM_{2.5}$ nonroad emissions is 19 percent and 20 percent respectively.

[14] The PM NAAQS referred to here is the 50 ug/m^3 (annual mean) 150 ug/m^3 (daily mean) standard.

Table 2-3
Summary by Source Category of National Annual Emission Projections to 2010 (thousand tons)

Pollutant	Source Category	1990	2010 Pre-CAAA	2010 Post-CAAA	% Change
VOC	Utility	37	49	50	2%
	Point	3,500	4,200	3,500	-19%
	Area	10,000	13,000	8,500	-36%
	Nonroad	2,100	2,600	1,900	-28%
	Motor Vehicle	6,800	7,300	3,900	-46%
	TOTAL	23,000	28,000	18,000	-35%
NO_x	Utility	7,400	9,100	3,800	-58%
	Point	2,900	3,600	2,200	-39%
	Area	2,200	3,000	3,000	-1%
	Nonroad	2,800	3,400	2,700	-20%
	Motor Vehicle	7,400	9,100	5,600	-39%
	TOTAL	23,000	28,000	17,000	-39%
CO	Utility	330	450	460	2%
	Point	6,000	7,400	7,400	0%
	Area	12,000	14,000	14,000	0%
	Nonroad	14,000	19,000	18,000	-4%
	Motor Vehicle	62,000	66,000	42,000	-37%
	TOTAL	94,000	107,000	82,000	-23%
SO_2	Utility	16,000	18,000	9,900	-44%
	Point	4,600	6,000	6,000	0%
	Area	1,000	1,500	1,500	0%
	Nonroad	240	240	240	0%
	Motor Vehicle	570	770	410	-47%
	TOTAL	22,000	26,000	18,000	-31%
Primary PM_{10}	Utility	280	310	280	-9%
	Point	930	1,200	1,200	0%
	Area	26,000	27,000	26,000	-3%
	Nonroad	340	410	340	-19%
	Motor Vehicle	360	300	210	-31%
	TOTAL	28,000	29,000	28,000	-3%
Primary $PM_{2.5}$	Utility	110	120	110	-8%
	Point	590	750	750	0%
	Area	5,800	6,300	6,100	-2%
	Nonroad	290	360	290	-20%
	Motor Vehicle	290	230	140	-39%
	TOTAL	7,100	7,700	7,400	-4%

NOTES: Table may not sum due to rounding. Percentage change was calculated prior to rounding.

to regulate NH_3. As a result, the Pre- and Post-CAAA estimates follow a similar upward trend. We estimate NH_3 emissions will increase roughly 55 percent from 1990 to 2010. Although we do not estimate the costs and benefits associated with NH_3 controls and changes in NH_3 ambient concentrations as part of this analysis, estimation of NH_3 emissions is an important part of the prospective study. NH_3 is a secondary PM precursor, and we relied on future-year NH_3 emissions estimates as model input to help us estimate PM concentrations.

We also estimated the effect of CAAA provisions on mercury (Hg) emissions for five separate Hg emissions sources: medical waste incinerators (MWI), municipal waste combustors (MWCs), electric utility plants, hazardous waste combustors, and chlor-alkali plants.[15] Together, these sources account for 75 to 80 percent of national anthropogenic airborne Hg emissions. In this analysis we qualitatively examine the effects of mercury emissions reductions on ecological systems (see Chapter 7 and Appendix E). We do not, however, evaluate the impact of Hg on human health.

Table 2-4 displays, for each emission category, base-year (1990) and future-year (2000 and 2010) Pre- and Post-CAAA emissions estimates. The table also shows the difference between Pre- and Post-CAAA estimates for each projection year. Overall, the results of this analysis indicate that the 1990 Amendments will provide a reduction in Hg emissions of 44.2 tons per year (tpy) in the year 2000 and a reduction of 56.2 tpy in 2010. These changes represent a 35 percent reduction in airborne mercury emissions for the year 2000 and a 42 percent reduction for 2010. We estimate that most of the reduction will be the result of New Source Performance Standards for MWI and MWCs.

Table 2-4
Airborne Mercury Emission Estimates

Source Category	1990 Emissions (tons)	2000 Emissions (tons) Pre-CAAA	2000 Emissions (tons) Post-CAAA	2000 Emissions (tons) Diff.	2010 Emissions (tons) Pre-CAAA	2010 Emissions (tons) Post-CAAA	2010 Emissions (tons) Diff.
Medical Waste Incin.	50	17.9	1.3	16.6	22.6	1.6	21.0
Municipal Waste Comb.	54	31.2	5.5	25.7	33.8	6.0	27.8
Electric Utility Generation	51.3	63.0	61.1	1.9	68.5	65.4	3.1
Hazardous Waste Comb.	6.6	6.6	6.6	0	6.6	3.0	3.6
Chlor-Alkali Plants	9.8	6.0	6.0	0	2.0	1.3	0.7
Total CAAA Benefits (Reductions)				**44.2**			**56.2**

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[15] With the exception of electric utility plant Hg emissions that were estimated using IPM, we relied on previously generated estimates (typically from recently conducted RIAs) to evaluate the impact of the CAAA on Hg emissions. For a more complete discussion of the methodology, see Appendix A.

Figure 2-1
Pre- and Post-CAAA Scenario VOC Emissions Estimates

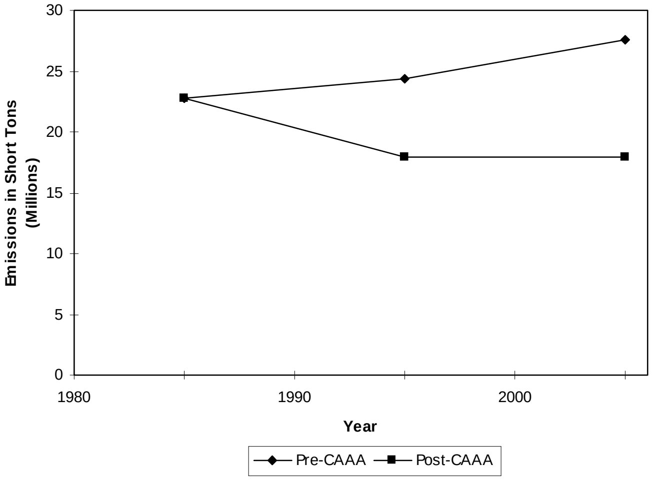


Figure 2-2
Pre- and Post-CAAA Scenario NO_x Emissions Estimates

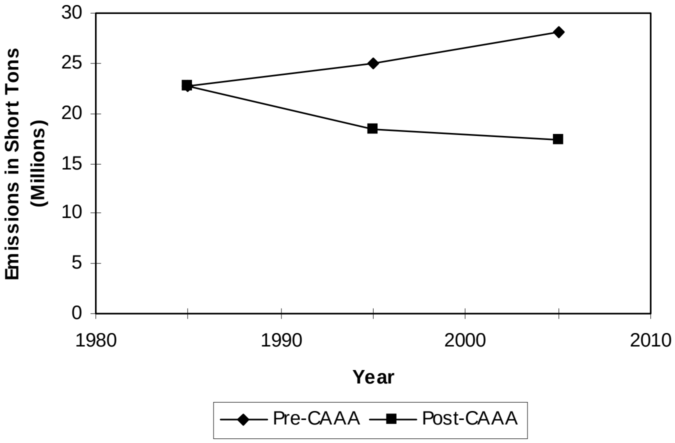


Figure 2-3
Pre- and Post-CAAA Scenario SO_2 Emissions Estimates

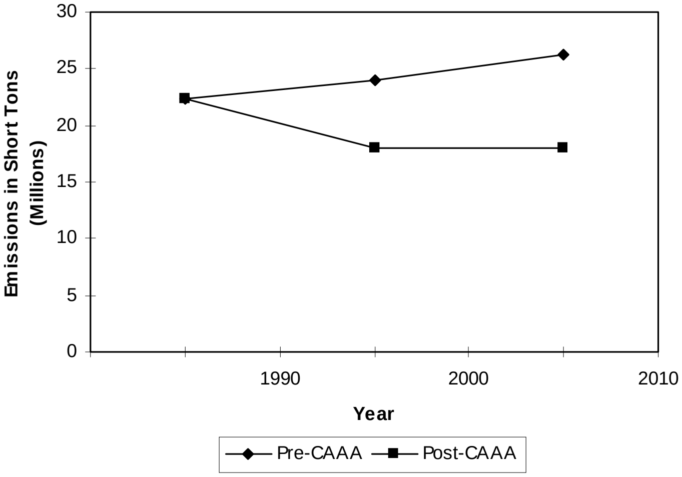


Figure 2-4
Pre- and Post-CAAA Scenario CO Emissions Estimates

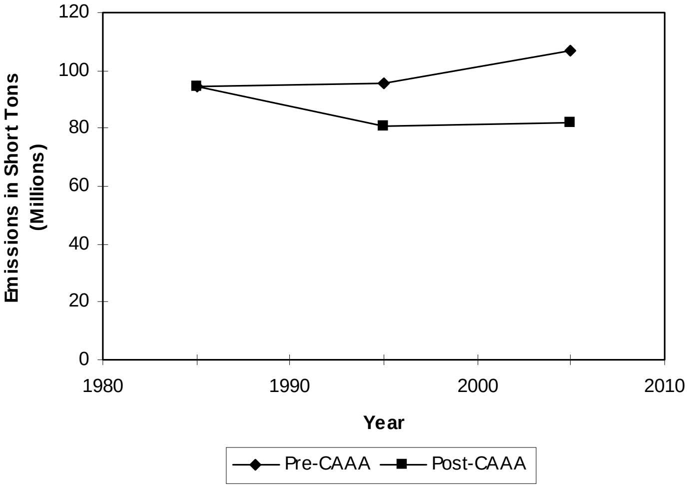


Figure 2-5
Pre- and Post-CAAA Scenario Primary PM$_{10}$ Emissions Estimates

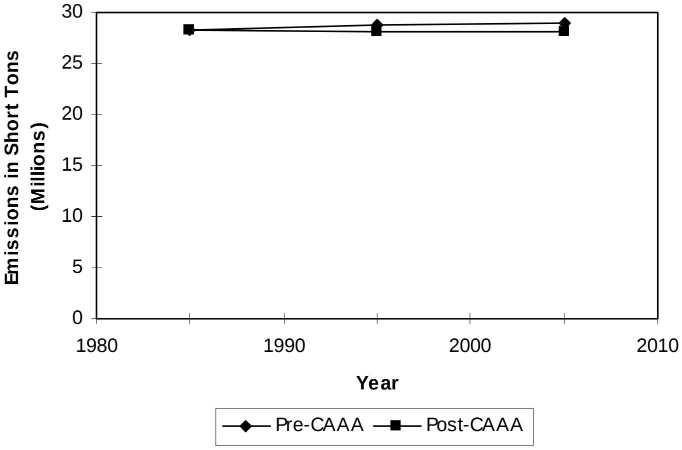
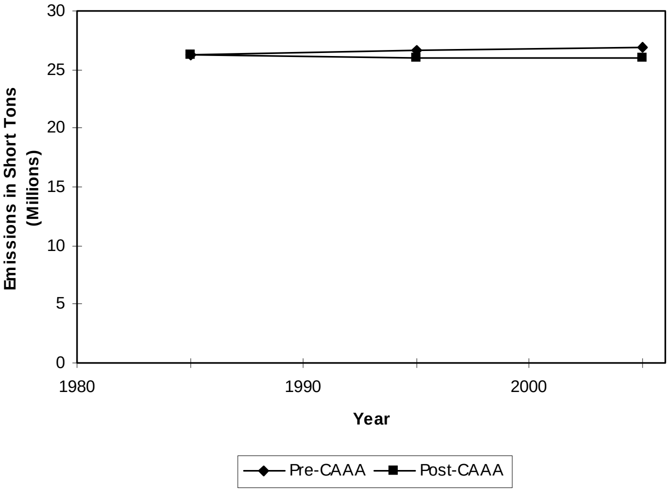


Figure 2-6
Pre- and Post-CAAA Scenario Primary PM$_{2.5}$ Emissions Estimates



Comparison of Emissions Estimates With Other Existing Data

Comparison of the emissions projections generated by the prospective analysis to historical emissions estimates drawn from the National Air Pollutant and Emissions Trends reports (*Trends*) provides a check on the reasonableness of our emissions inventories. In addition, comparison of emissions projections from the prospective analysis with those of the Grand Canyon Visibility Transport Commission (GCVTC) study of western regional haze provides an initial test of the sensitivity of emissions projections to base-year inventories and growth assumptions. Analysis of PM emissions and comparison of estimated and observed PM data also help us evaluate the prospective study's emissions estimation methods.

Trends reports contain historical estimates of annual VOC, NO_x, SO_2, CO, and PM_{10}, emissions. While the most recent report only provides emissions data through the first half of the 1990s, comparison of these estimates from 1990 to 1996 with emissions trends projected under the Post-CAAA scenarios reveals that emissions figures from both are similar. The disparity that does exist between the two sets of estimates largely stems from the fact that the Post-CAAA scenario trend lines running from 1990 to 2000 consist of only two data points. As a result, Post-CAAA trend lines cannot capture yearly fluctuations in emissions and the exact timing of emissions cuts. Only for NO_x are the *Trends* and Post-CAAA estimates significantly different; this is because the *Trends* report is still in the process of incorporating the State's periodic emission inventory into the NET database. As a result, *Trends* values do not capture all the NO_x emission reductions that have occurred since 1990. For example, significant reductions attributable to reasonable available control technology (RACT) requirements for major stationary source NO_x emitters areas are not reflected in the *Trends* figures.

The Grand Canyon Visibility Transport Commission conducted an air pollution analysis for Western States that projected emissions for selected pollutants, including NO_x, SO_2, and $PM_{2.5}$, from 1990 base-year levels for the year 2000 and every tenth subsequent year up to 2040. GCVTC estimates of future-year emissions levels differ from Post-CAAA projections. This disparity results from the use of different base-year inventories in the two studies and from specific regional reductions not incorporated in the prospective analysis scenarios. Despite the difference in GCVTC and Post-CAAA estimates, the change in the level of emissions from 1990 to 2010 predicted by the two studies is similar. Comparison of both sets of projections illustrates the sensitivity of future-year emissions estimates to the base-year inventory.

The 1997 National Air Quality and Emissions Trends Report provides a summary of $PM_{2.5}$ concentration speciation data. This report shows the relative contribution of the major PM emissions source components (crustal material, carbonaceous particles, nitrate, and sulfate) to ambient $PM_{2.5}$ concentrations in urban and nonurban areas throughout the U.S.[16] Comparison of primary $PM_{2.5}$ emissions estimates generated for this analysis with the observed concentration data presented in the 1997 report indicates that the ratio in the prospective study of crustal material to primary carbonaceous particles is high. At least part of this apparent overestimation of crustal material and underestimation of carbonaceous particulates, however, is due to the fact that much of the emitted crustal material quickly settles and does not have a quantifiable impact on ambient air quality. In this analysis, we apply a factor of 0.2 to crustal emissions to estimate the fraction of crustal $PM_{2.5}$ that makes its way into the "mixed layer" of the atmosphere and influences pollutant concentrations. Figure 2-7 displays the breakout of primary $PM_{2.5}$ into its adjusted crustal and carbonaceous (elemental carbon and organic carbon) components. The figure divides crustal material into two subcategories, fugitive dust or industrial sources, based on the source of the material and also shows the fraction of primary $PM_{2.5}$ that is

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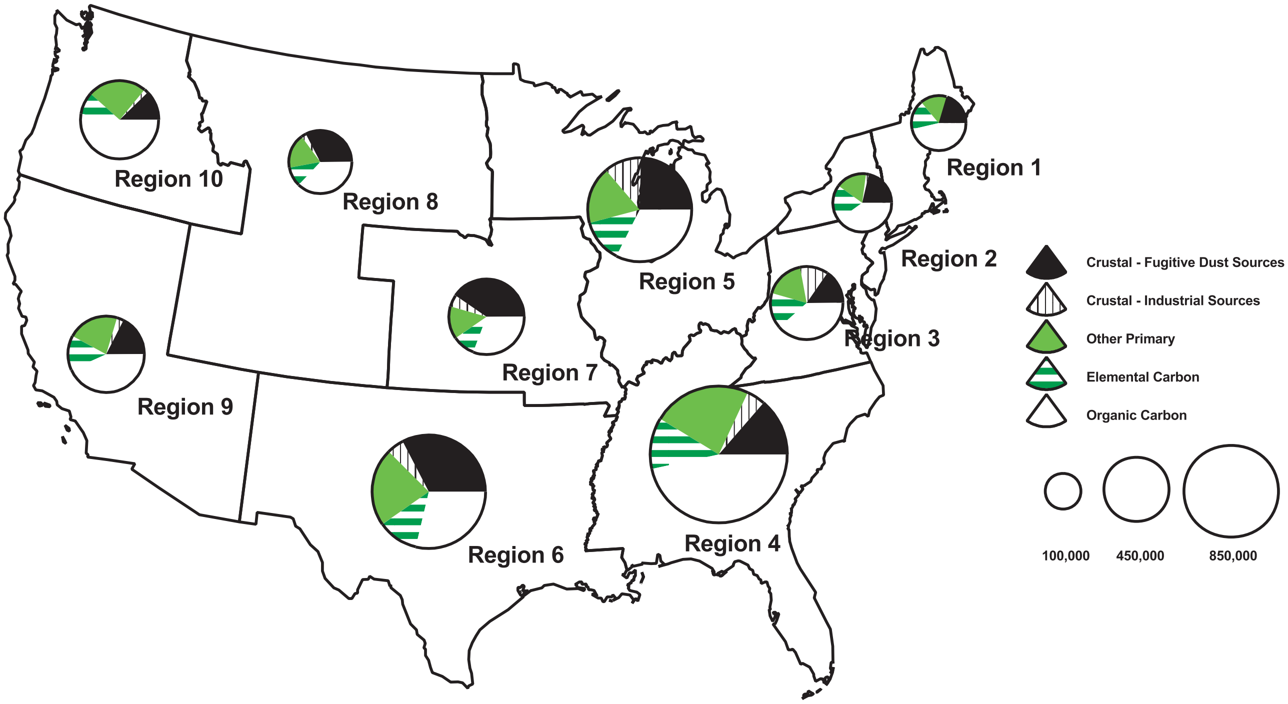
[16] Crustal material is directly emitted from fugitive dust sources such as agricultural operations, construction, paved and unpaved roads, and wind erosion as well as from some industrial sources such as metals processing. Carbonaceous particles, as defined in the 1997 National Air Quality and Emissions Trends Report," are emitted directly and as condensed liquid droplets from fuel combustion, burning of forests, rangelands, and fields; off highway and highway mobile sources (gas and diesel); and certain industrial processes".

Figure 2-7
1990 Primary $PM_{2.5}$ Emissions by EPA Region (tons/year)



neither crustal nor carbonaceous. The ratios of adjusted crustal material to primary carbonaceous particles presented in Figure 2-7 are in line with the observed $PM_{2.5}$ concentration data presented in the 1997 report.

Uncertainty In Emission Estimates

Table 2-5 provides a list of sources of uncertainty associated with estimating base-year emissions, the expected direction of bias introduced by each uncertainty (if known), and the relative significance of each uncertainty in the overall 812 benefits analysis. The emissions estimates presented in the prospective analysis are characterized by three major sources of uncertainty: estimation of the base-year inventory, prediction of the growth in pollution-generating activity, and assumptions about future-year controls.

Base-year emissions were estimated using emissions factors that express the relationship between a particular human/industrial activity and the level of emissions. The accuracy of base-year emissions estimates varies from pollutant to pollutant, depending largely on how directly the selected activity and emissions correlate. We likely estimated 1990 SO_2 emissions with the greatest precision. Sulfur dioxide emissions are generated during combustion of sulfur-containing fuel and are directly related to fuel sulfur content. In addition, we were able to verify these estimates through comparison with Continuous Emission Monitoring (CEM) data. As a result, we were able to accurately estimate SO_2 emissions using emissions factors based on data on fuel usage and fuel sulfur content. Nitrogen oxides are also a product of fuel combustion, allowing us to estimate emissions of this pollutant using the same general technique used to estimate SO_2 emissions. However, the processes involved in the formation of NO_x during combustion are more complicated than those involved in the formation of SO_2; thus, our NO_x emissions estimates are more variable and less certain than SO_2 estimates.

Volatile organic compounds, like SO_2 and NO_x, are products of fuel combustion; however, these compounds are also a product of evaporation. To estimate evaporative emissions of this pollutant we used emissions factors that relate changes in emissions to changes in temperature. Because future meteorological conditions are difficult to predict, the uncertainty associated with forecasting temperature influences the uncertainty in our VOC emissions estimates. The likely significance of this uncertainty, in terms of its impact on the overall monetary benefit present in this analysis, is probably minor.

In this analysis we estimated primary $PM_{2.5}$ emissions based on unit emissions that may not accurately reflect the composition and mobility of particles. The ratio of crustal to carbonaceous particulate material, for example, likely is high as a result of overestimation of the fraction of crustal material, primarily composed of fugitive dust, and underestimation of the fraction of carbonaceous material. Because the CAAA has a greater impact on emissions sources that generate carbonaceous particles (mobile sources) than on sources that mainly emit crustal material (area sources), we likely underestimate the impact of the CAAA on reducing $PM_{2.5}$, thereby reducing monetary benefits estimates. The uncertainty associated with estimating the partition of $PM_{2.5}$ emissions components could conceivably have a major impact on the net benefit estimate; compared to secondary $PM_{2.5}$ precursor emissions, however, changes in primary $PM_{2.5}$ emissions have a relatively small impact on $PM_{2.5}$ related benefits.

We estimated future-year emissions levels based on expected growth in pollution-generating activities. Inherent uncertainties and data inadequacies/limitations exist in forecasting growth for any future period. Also, the growth indicators we used in this analysis may not directly correlate with changes in the factors that influence emissions. Both of these factors contribute to the uncertainty associated with this study's emissions results. For example, the best indicator of pollution-generating activity is fuel use or some other measure of input/output that most directly relates to emissions. The key BEA indicator used in this analysis, GSP, is closely correlated with the pollution-generating activity associated with many manufacturing industry processes (iron and steel, petroleum refining, etc.). However, a good portion of industrial sector emissions are from boilers and furnaces, whose activity is related to production, but not as closely as to product output. Activities such as fuel switching may produce different emission patterns than those reflected in the results of this study.

Our future-year control assumptions are also a source of uncertainty. Despite our efforts to minimize this uncertainty, whether each of the Post-CAAA controls will be adopted, whether Post-CAAA control programs will be more or less effective than estimated, and whether unanticipated technological shifts will reduce future-year emissions are all unknown. For example, the Post-CAAA scenario includes implementation of a region-wide NO_x control strategy designed to regulate the regional transport of ozone. However, the control program assumed under the Post-CAAA scenario may not reflect the NO_x controls that are actually implemented in a regional ozone transport rule.

Table 2-5
Key Uncertainties Associated with Emissions Estimation

Potential Source of Error	Direction of Potential Bias for Net Benefits Estimate	Likely Significance Relative to Key Uncertainties in Net Benefit Estimate*
$PM_{2.5}$ emissions are largely based on scaling of PM_{10} emissions.	Overall, unable to determine based on current information, but current emission factors are likely to underestimate $PM_{2.5}$ emissions from combustion sources, implying a potential underestimation of benefits.	Potentially major. Source-specific scaling factors reflect the most careful estimation currently possible, using current emissions monitoring data. However, health benefit estimates related to changes in $PM_{2.5}$ constitute a large portion of overall CAAA-related benefits.
Primary $PM_{2.5}$ emissions estimates are based on unit emissions that may not accurately reflect composition and mobility of the particles. For example, the ratio of crustal to primary carbonaceous particulate material likely is high.	Underestimate. The effect of overestimating crustal emissions and underestimating carbonaceous when applied in later stages of the analysis, is to reduce the net impact of the CAAA on primary $PM_{2.5}$ emissions by underestimating $PM_{2.5}$ emissions reductions associated with mobile source tailpipe controls.	Potentially major. Mobile source primary carbonaceous particles are a significant contributor to public exposure to $PM_{2.5.}$ Overall, however, compared to secondary $PM_{2.5}$ precursor emissions, changes in primary $PM_{2.5}$ emissions have only a small impact on $PM_{2.5}$ related benefits.
The Post-CAAA scenario includes implementation of a region-wide NO_x emissions reduction strategy to control regional transport of ozone that may not reflect the NO_x controls that are actually implemented in a regional ozone transport rule.	Unable to determine based on current information.	Probably minor. Overall, magnitude of estimated emissions reductions is comparable to that in expected future regional transport rule. In some areas of the 37 state region, emissions reductions are expected to be overestimated, bur in other areas, NO_x inhibition of ozone leads to underestimates of ozone benefits (e.g., some eastern urban centers).
VOC emissions are dependent on evaporation, and future patterns of temperature are difficult to predict.	Unable to determine based on current information.	Probably minor. We assume future temperature patterns are well characterized by historic patterns, but an acceleration of climate change (warming) could increase emissions.
Use of average temperatures (i.e., daily minimum and maximum) in estimating motor-vehicle emissions artificially reduces variability in VOC emissions.	Unable to determine based on current information.	Probably minor. Use of averages will overestimate emissions on some days and underestimate on other days. Effect is mitigated in Post-CAAA scenarios because of more stringent evaporative controls that are in place by 2000 and 2010.

Table 2-5 (continued)
Key Uncertainties Associated with Emissions Estimation

Potential Source of Error	Direction of Potential Bias for Net Benefits Estimate	Likely Significance Relative to Key Uncertainties in Net Benefit Estimate*
Economic growth factors used to project emissions are an indicator of future economic activity. They reflect uncertainty in economic forecasting as well as uncertainty in the link to emissions.	Unable to determine based on current information.	Probably minor. The same set of growth factors are used to project emissions under both the Pre-CAAA and Post-CAAA scenarios, mitigating to some extent the potential for significant errors in estimating differences in emissions.
Uncertainties in the stringency, scope, timing, and effectiveness of Post-CAAA controls included in projection scenarios.	Unable to determine based on current information.	Probably minor. Future controls could be more or less stringent, wide-reaching (e.g., NO_x reductions in OTAG region - see above), or effective (e.g., uncertainty in realizing all Reasonable Further Progress requirements) than projected. Timing of emissions reductions may also be affected (e.g., sulfur emissions reductions from utility sources have occurred more rapidly than projected for this analysis).

* The classification of each potential source of error reflects the best judgement of the section 812 Project Team. The Project Team assigns a classification of "potentially major" if a plausible alternative assumption or approach could influence the overall monetary benefit estimate by approximately five percent or more; if an alternative assumption or approach is likely to change the total benefit estimate by less than five percent, the Project Team assigns a classification of "probably minor."

Direct Costs

Chapter 3

The costs of complying with the requirements of the Clean Air Act Amendments (CAAA) of 1990 will affect all levels of the U.S. economy. The impact, initially experienced through the direct costs imposed by regulations promulgated under the amendments, will also be seen in patterns of industrial production, research and development, capital investment, productivity, employment, and consumption. The purpose of the analysis summarized in this chapter is to estimate the incremental change in annual compliance costs from 1990 to 2010 that are directly attributable to the 1990 Clean Air Act Amendments.

This chapter consists of four sections. The first section summarizes our approach to estimating direct compliance costs. In the second section we present the results of the cost analysis. We first report the total costs of Titles I through V and then present estimates for major individual provisions. We also briefly discuss our derivation of Title VI costs. In the third section, we provide a qualitative discussion of the potential magnitude of social costs and other impacts associated with the Amendments to characterize the potential welfare loss not captured in the direct cost approach. We conclude the chapter with a discussion of the major analytic uncertainties and include the results of quantitative sensitivity tests of key data and assumptions.

Approach to Estimating Direct Compliance Costs

As discussed in the previous chapter, the first step of the prospective analysis required the development of emission estimates for the base-year, 1990, and for the two target years in our analytic time period, 2000 to 2010. We developed two scenarios, Pre-CAAA and Post-CAAA, that reflect three key parameters: (i) base-year inventory selection, (ii) indicators of forecasted economic growth, and (iii) effects of future year controls and selected CAAA provisions. The Pre-CAAA scenario applies the stringency and scope of air pollution regulations as they existed in 1990 and projects emissions and costs to 2000 and 2010. This scenario establishes a baseline that represents projected emission levels and control costs in the absence of the 1990 Amendments. Under the Post-CAAA scenario, costs are based on compliance with selected CAAA provisions. Together these two scenarios form the foundation upon which the incremental costs and benefits of complying with the 1990 Amendments are estimated. For more information on the development of these scenarios, see Chapter 2.

We closely integrate the modeling of direct compliance costs with emissions projections by maintaining consistency among control assumptions (i.e. emissions scenarios) used as inputs in the cost estimation modeling and in the analysis of emissions projections and benefits. We use two models to estimate costs, Emission Reduction and Cost Analysis Model (ERCAM) and Integrated Planning Model (IPM). These models generate cost estimates for the Post-CAAA scenarios in two projection years, 2000 and 2010. The estimates are calculated relative to costs under the same year Pre-CAAA scenario, so estimates represent incremental costs of compliance with the 1990 Amendments.

We use ERCAM to estimate costs associated with regulating particulate matter (PM), volatile organic compounds (VOCs), and non-utility source oxides of nitrogen (NO_x).[1] The model is essentially a cost-accounting tool that provides a structure for modifying and updating changes in inputs while main-

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[1] This model was developed by E. H. Pechan & Associates, Inc. to facilitate EPA's analysis of emissions control.

taining consistency with the emission and cost analyses. Cost scenarios and assumptions are developed for each non-utility source category (e.g., point, area, nonroad, and motor vehicle sources) and in response to specific provisions and emission targets. The model estimates costs based on inputs such as cost per ton, source-specific cost equations, incremental production, and operating cost estimates. For this analysis, we collected data and inputs from information presented in regulatory impact assessments (RIAs), background information documents (BIDs), regulatory support documents, and Federal Register notices.

To estimate the costs of reducing utility NO_x and sulfur dioxide (SO_2) emissions, we use the Integrated Planning Model (IPM). IPM allows us to estimate the control costs of several pollutants while maintaining consistent control scenarios and economic forecasts of the electric power industry. It assesses the optimal mix of pollution control strategies subject to a series of specified constraints. Key inputs and constraints in the model include targeted emissions reductions (on a seasonal or annual basis), costs and constraints of control technology, and economic parameters (e.g., forecasted demand for electricity, power plant availability/capacity, costs of fuel, etc.)

To assess the costs of reducing emission of pollutants or sectors not covered by our two models, we estimate costs using the best available cost equations or other types of analyses. For example, we estimate non-utility SO_2 emission control costs for point sources by applying source-specific cost equations for flue gas desulfurization (FGD)/scrubber technology to affected sources in 2000 and 2010. While we do not explicitly model CO attainment costs, we include in the analysis the costs of programs designed to reduce CO emissions, such as oxygenated fuels and a cold temperature CO motor vehicle emission standard. Finally, to estimate costs of the rate of progress/reasonable further progress (ROP/RFP) provisions, requirements under Title I that require ozone nonattainment areas to make steady progress toward attainment, we first estimate the emissions reduction shortfall that must be achieved in each target year in each nonattainment area, and then apply a cost per ton estimate from a schedule of measures that could be applied locally to meet the necessary ROP/RFP requirement. For more detail on the specific methods used to estimate compliance costs for each pollutant and source category, see Appendix B.

The cost estimates in this chapter are the incremental costs of the 1990 Amendments (i.e. the difference between pre- and Post-CAAA cost estimates). We present the results as total annualized costs (TAC) in 2000 and 2010. Annualized costs include both capital costs, such as costs of control equipment, and operation and maintenance (O&M) costs.[2] They do not represent actual cash flow in a given year, but are rather an estimate of average annual burden over the period during which firms will incur costs. In annualizing costs, we convert total capital investment to a uniform series of total per-year equivalent payments over a given time period using an assumed real cost-of-capital at five percent. We then add O&M and other reoccurring costs to the annualized capital cost to arrive at TAC. The discounted sum of these annual expenditures is equal to the net present value of total costs incurred over the time period of this analysis.[3]

Direct Compliance Cost Results

Total annual compliance costs for Titles I through V of the 1990 Amendments in the year 2000 will be approximately \$19.4 billion; the estimate increases to \$26.8 billion in the year 2010. These costs reflect "annualized" operation and maintenance (O&M) expenditures (which includes research and development (R&D) and other similarly recurring expenditures) plus amortized capital costs (i.e., depreciation plus interest costs associated with the ex-

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[2] For a few VOC source categories, we estimate that capital investment will not be necessary; for these sources, compliance costs reflect O&M costs only.

[3] We recalculate the control cost estimates from regulatory documents that use a seven or ten percent discount rate so that the costs will be consistent with the five percent discount rate assumption used in this analysis. We also calculate cost using three percent and seven percent discount rates, as sensitivity tests; for detail see the discussion of uncertainty later in this chapter, in Chapter 8, and in Appendix B.

isting capital stock) for the particular year.[4] We present cost estimates by title and emissions source category (point sources, area sources, utilities, nonroad engines and vehicles, and motor vehicles) in Table 3-1.

In some cases, assigning costs to a single CAAA title is complicated by the fact that there are rules issued pursuant to more than one title.[5] In addition, with the passage of the 1990 Amendments, the States were given greater discretion in developing CAAA compliance strategies. For example, the States can determine how best to meet progress requirements and are responsible for creating permit programs (under Title V). As a result, a significant portion of the costs also represent State-level strategies and decisions for reducing emissions.

Title I, Provisions for Attainment and Maintenance of National Ambient Air Quality Standards (NAAQS), represents pollution controls (of VOC, NO_x, and PM emissions) implemented primarily by point and area sources. Title I provisions also account for State programs designed to meet progress requirements. By 2010, we project the costs of Title I provisions will account for over half of total CAAA direct compliance costs ($14.5 billion). An additional 34 percent of estimated total costs ($9 billion) is attributed to regulating mobile source emissions under Title II. Collectively, the combined direct compliance costs of these two titles is $16 billion in 2000 and $23 billion by 2010.

The remaining three titles account for less than 20 percent of total CAAA direct costs. We estimate that Title III provisions, which target hazardous air pollutant (HAP) emissions, will cost $840 million by the year 2010. This estimate represents total annualized capital costs (TACs) for individual two- and four-year MACT standards. While the majority of this estimated cost reflects reducing VOC emissions (since HAP emissions were not included as part of the Section 812 base- year inventory), Title III costs do include some costs of final MACT rules that regulate non-VOC HAP emissions.

In order to estimate the costs associated with Title IV, we considered the implications of pollution abatement controls (for SO_2 and NO_x) on the electric power industry's operation of generation units and how, over time, this would affect the demand for electricity. The annual compliance estimate for Title IV costs is $2.3 billion in 2000. This estimate decreases to $2.0 billion by 2010. This decrease reflects, in part, the future compliance cost savings resulting from the SO_2 allowance trading program.

Title V costs are associated with new operating permit programs. The estimate accounts for approximately one percent of total costs projected under the Post-CAAA 2010 scenario. States are expected to implement Title V permit programs by 2005. The estimate reflects the costs of State-developed programs during the first five-year implementation period. These costs include incremental administrative costs incurred by the permitted sources, State and local permitting agencies, and EPA. The estimate excludes federally-implemented State programs and state programs which were already established in the baseline.

Our presentation of cost estimates for the stratospheric ozone protection provisions of Title VI is, by necessity, different from other titles. Ideally, one should compare the costs of actions taken in a given year to the benefits attributable to these actions. For Title VI, a cost-benefit comparison of any given year requires assumptions that result in potentially misleading figures. The difficulty is due to the differing time horizons and the complexity of the process by which ozone-depleting substances (ODSs) cause adverse effects on human health and the environment. Title VI provisions incur costs over significantly varying time horizons; for example, the cost analysis of Sections 604 and 606 provisions spans 85 years (from 1990 to 2075). At the same time, the analysis of Section 611 extends from 1994 to 2015. In response to this analytic difficulty, we base our comparison of Title VI costs to Title VI benefits on net present values.

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[4] Capital expenditures are investments, generating a stream of benefits and opportunity costs over an investment's lifetime. In a cost-benefit analysis, the appropriate accounting technique is to annualize capital expenditures. This technique involves spreading the costs of capital equipment uniformly over the useful life of the equipment, by using a discount rate to account for the time value of money. In this analysis, all capital expenditures were annualized using a real five percent interest rate.

[5] In those cases, we generally assigned costs to a single title based upon implementation dates and the year by which emission reductions are expected.

Table 3-1
Summary of Direct Costs for Titles I to V of CAAA, By Title and Selected Provisions
(Annual Costs in million 1990$)

Title/Provision	Primary Cost Estimate 2000	Percentage of Total Costs	Primary Cost Estimate 2010	Percentage of Total Costs
Title I- Provisions for Attainment and Maintenance of NAAQS				
Stationary NO_x Controls, Utility Industry	$ 790	4%	$ 2,500	9%
Progress Requirements	1,200	6%	2,500	9%
PM NAAQS Controls	1,900	10%	2,200	8%
California LEV	320	2%	1,100	4%
National LEV	180	1%	1,100	4%
High Enhanced I/M	1,100	6%	1,400	5%
Other Title I Programs	3,100	16%	3,700	14%
Title I: Total Costs	$ 8,600	44%	$ 14,500	54%
Title II- Provisions Relating to Mobile Sources				
California Reformulated Gasoline	$ 2,000	10%	$ 2,400	9%
NO_x Tailpipe/Extended Useful Life Standard	1,500	8%	1,700	6%
Other Title II Programs	3,900	20%	4,900	18%
Title II: Total Costs	$ 7,400	38%	$ 9,050	34%
Title III- Hazardous Air Pollutants				
Title III: Total Costs	$ 780	4%	$ 840	3%
Title IV- Acid Deposition Control				
Title IV: Total Costs	$ 2,300	12%	$ 2,040	8%
Title V- Permits				
Title V: Total Costs	$ 300	2%	$ 300	1%
Total Annual Cost	$ 19,400	100%	$ 26,800	100%

Note: Totals may not sum due to rounding. Only major provisions are listed under each title - other, less costly provisions not listed here are nonetheless included in the totals by title and the overall total.

The net present value of Title VI program costs reflect selected actions and their associated costs from Sections 604, 606, 608, 609, and 611. Examples of these actions include: replacement of ozone-depleting chemicals with alternative technologies and materials; recycling and storage of unused chlorofluorocarbons; labeling; training; and administration. Using a discount rate of five percent and a 85-year time horizon (from 1990 to 2075), we estimate the net present value of Title VI costs is $27 billion. For illustrative purposes, we calculated an annualized estimate of Title VI costs. It is, however, important to recognize that these estimates may overestimate actual compliance costs in those years, especially in the year 2000, because of the phased nature of implementation— see Appendix G for more details. Our annualized estimate of total Title VI costs is $1.4 billion. This value reflects an annualized equivalent value of costs incurred over 85 years (from 1990 to 2075) using a five percent discount rate.

Selected Provisions

Our analysis indicates eight provisions will account for approximately 54 percent of the total direct compliance costs estimate for 2010. Six are Title I provisions that affect stationary sources and vehicle emissions. The remaining two provisions target mobile sources under Title II. These provisions are:

- PM NAAQS controls[6],
- Electric power industry compliance (stationary NO_x control),
- Progress Requirements,
- California Low Emission Vehicle (LEV)program,
- National Low Emission Vehicle (LEV) program,
- High Enhanced Inspection and Maintenance (I/M) program,
- California Reformulated Gasoline, and
- NO_x Tailpipe/Extended Useful Life Standard.

The 1990 CAAA regulates stationary source emissions primarily under Title I. Among the relevant provisions, PM NAAQS, utility industry compliance with NO_x standards, and progress requirements are the main sources of Title I costs. From 2000 to 2010, we estimate the control costs of all three provisions will increase by at least a factor of two. Under the Post-CAAA scenario developed for the emissions analysis, the utility industry's compliance with NO_x emission standards affects all electric generation units using fossil fuels. Existing oil and gas units face Reasonable Available Control Technology (RACT) requirements and all new units must comply with more stringent New Source Performance Standards (NSPS) and New Source Review (NSR) requirements. By 2010, estimated costs for stationary NO_x controls more than triple ($790 million to $2,500 million). The cost estimate indicates that the provision will be the single largest source of CAAA direct costs. The second largest component of total costs in 2010 is attributed to progress requirements. Annual compliance costs with progress requirements double from 2000 to 2010 ($1.2 billion and $2.5 billion, respectively). Among the three provisions, the annual costs associated with PM NAAQS compliance exhibits the least amount of growth. We estimate annual costs for PM NAAQS compliance will grow from $1.9 billion in 2000 to $2.2 billion in 2010.

Among the provisions regulating vehicle emissions, only the national and California LEV programs exhibit a trend of increasing direct costs of the same magnitude as seen with the costs of regulating stationary sources under Title I. The combined cost of national and California LEV programs is $2.2 billion in 2010. For the California LEV program, the increase in cost is largely a function of higher per vehicle cost estimates (e.g., zero emission vehicles (ZEV) are mandated in the year 2003). Our cost analysis of the national LEV program assumes that only the Northeast Ozone Transport Region (OTR) states will incur costs in the year 2000. By 2010, however, we expect that the program will affect areas outside of the OTR. As a result, 2010 national LEV costs increase with the expected expansion and increased volume of vehicle sales. Unlike many of the other provisions, high enhanced I/M costs do not exhibit significant growth from 2000 to 2010. We estimate this provision accounts for approximately six percent of total costs in 2000 and five percent in 2010. These costs, however, are uncertain pending State decisions regarding the design of their programs.

Among the analyzed Title II provisions, we attribute nearly 15 percent of total annual direct costs to the California reformulated gasoline (RFG) program and NO_x Tailpipe/Extended Useful Life Standard. Although the reformulated gasoline program affects only California, the state accounts for nearly ten percent of annual gasoline sales in the United States. We estimate compliance costs of $1.9 billion in the year 2000. As the program enters Phase 2, estimated costs grow to $2.4 billion. The trend in cost associated with NO_x Tailpipe/Extended Useful Life Standard is very different. While costs increase slightly between the years 2000 and 2010, the provision's share of total cost slightly decreases.

Characterization of Other Economic Impacts

In an ideal setting, a cost-benefit analysis would not only identify, but also quantify and monetize, an exhaustive list of social costs associated with a regulatory action. This would include assessing how regulatory actions targeting a specific industry or set of facilities can alter the level of production and consumption in the directly affected market and related

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[6] We estimate the PM NAAQS provision costs based on compliance with standards that were in effect prior to 1997 revisions (62 Fed. Reg. 38,652, 1997).

markets. For example, regulation of emissions from the electric utility industry that results in higher electricity rates would have both supply-side and demand-side responses. In secondary markets, the increased electricity rates affect production costs for various industries and initiate behavioral changes (e.g., using alternative fuels as a substitute for electric power). With each affected market, there are also associated externalities that should be included in estimating social costs. Returning to the utilities example, the externalities associated with electric power generation versus nuclear power generation can be very different. The mix of externalities could change as consumers substitute nuclear power for electric power. It is frequently difficult to accurately characterize one or all of these dimensions of market responses and estimate the resulting social costs.

There are three generally practiced approaches to calculating costs associated with regulation: (i) direct compliance cost, (ii) partial equilibrium modeling, and (iii) general equilibrium modeling. Direct compliance cost estimates are calculated differently than the economic welfare impact estimates that result from partial or general equilibrium modeling; a direct cost estimate is often the most straightforward of the three approaches. This method estimates compliance expenditures or, in economic terms, how an industry's or firm's marginal cost curve shifts due to increased production costs associated with regulatory compliance. As a result, this method does not account for firm responses and market responses, such as adjustment of production levels and product prices. The other two methods measure changes in producer and consumer welfare, and incorporate these types of adjustments.

The direct cost approach likely overstates actual compliance expenditures, but may have an ambiguous relationship to total social costs. There are two primary reasons for the overstatement of compliance expenditures. First, the direct cost approach does not account for market responses. As a result, total direct cost estimates reflect the incremental cost per unit of output multiplied by the generally higher, pre-regulation quantity produced. Second, a direct cost approach tends to make the simplifying assumption that firms rely on static pollution abatement technology, when in fact the presence of compliance costs provides an incentive to innovate. Several *ex post* cost analyses suggest that the marginal cost curve may not necessarily shift by the full amount of the pollution abatement. For example, firms may respond by altering production processes to more efficiently reduce emissions.[7] Social cost estimates, however, may include other costs not reflected in direct cost estimates (discussed below), thereby offsetting the tendency for direct cost estimates to overstate expenditures.

Measuring net welfare changes due to regulatory action requires either partial or general equilibrium modeling. These more complicated approaches estimate social costs by accounting for a wider range of market consequences associated with compliance with pollution abatement requirements. The partial equilibrium approach is particularly appropriate when social costs are predominantly incurred in directly affected markets. It requires modeling both supply and demand functions in the affected economic sector. Therefore, measures of social cost reflect behavioral responses by both producers and consumers in a specific market and do not necessarily reflect how those changes affect related markets.

In cases where the regulatory action is known to have an impact on many sectors of the US economy, the general equilibrium model is a more appropriate approach to estimating social costs. Like the partial equilibrium model, the general equilibrium model estimates social costs by accounting for direct compliance costs and producer and consumer market behavior. The general equilibrium model can capture first-order effects that occur in multiple sectors of the economy, and may also provide insight into unanticipated indirect effects in sectors that might not have been included in the scope of a partial equilibrium analysis.

The relationship of general equilibrium estimates to estimates from the other two cost approaches is not always clear. General equilibrium estimates have a broader basis from which to estimate social costs and can reflect the net welfare changes across the full range of economic sectors in the U.S. Partial equilibrium modeling tends to understate full social costs because of its restricted scope (i.e., generally limited to one industry). Total direct cost estimates are likely to overstate costs in the primary market because they do not reflect consumer and producer responses. This is demonstrated in comparisons of

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[7] Morgenstern *et al.* (1998) estimate the ratio of incurred abatement expenditures to estimated direct costs can be as low as 0.8.

estimates generated using a direct cost approach and a partial equilibrium approach. The extent to which a direct cost estimate will overstate or understate a social cost estimate from a general equilibrium model depends on the magnitude of the "ripple effects" in economic sectors not targeted by a regulation.[8]

In the 812 retrospective analysis (EPA, 1997), we recognized that the Clean Air Act has a pervasive impact on the US economy and opted for the general equilibrium approach. The retrospective nature of the analysis, however, provided us with fairly well-developed historical data sets of goods and service flows throughout the economy. These data sets facilitated the development of detailed, year-by-year expenditures in all sectors of the economy, from which we modeled producer and consumer behavior and estimated net social costs. In the retrospective, our central estimate of total annualized direct costs, from 1970 to 1990, was $523 billion. In comparison, we estimated the aggregate welfare effects to be between $493 and $621 billion.[9]

For the prospective analysis, however, we adopt a direct compliance cost approach. Although the general equilibrium approach may represent a more theoretically preferable method for measuring social costs, we use the simpler direct cost modeling method for three reasons:

- First, we believe that the direct cost approach provides a good first approximation of the CAAA's economic impacts on various sectors the U.S. economy. Comparison of the direct cost approach to the partial equilibrium modeling suggests that the direct cost approach likely overstates costs to the entity that incurs the pollution control cost expenditure. As discussed earlier, the direct cost approach does not reflect adjustments to prices and quantities that might mitigate the effects of regulation. Recent research analyzing ex ante and ex post cost estimates of regulations suggests that *ex ante* analyses are far more likely to overstate than understate costs.[10] However, direct cost estimates may also understate the effects of long-term changes in productivity and the ripple effects of regulation on other economic sectors that are captured by a general equilibrium approach. The magnitude of those other effects, including potential magnification of social costs by existing tax distortions, may be substantial.

- Second, we believe that the closer approximation of social costs that might be gained through a general equilibrium approach could be compromised by the difficulty and uncertainty associated with projecting future economic and technological changes. The general equilibrium approach could provide many insights that the direct cost approach cannot, but also introduces a significant level of additional uncertainty.

- Third, the focus of the present analysis is a comparison of direct costs and direct benefits. To provide a balanced treatment of costs and benefits in a general equilibrium framework, the social cost model must be designed and configured to reflect the indirect economic consequences of both costly and beneficial economic effects. None of the general equilibrium models available in the timeframe of this study could be configured to support effective analysis of the full range of specific direct costs and, especially, direct benefits of the 1990 Clean Air Act Amendments.

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[8] Current regulatory analyses that apply partial equilibrium modeling or general equilibrium modeling tend to measure costs with the assumption that markets are currently operating under optimally efficient conditions. Emerging literature suggests that a full accounting of the social costs and efficiency impacts of environmental regulations could also include an assessment of the incremental costs that reflect existing market distortions, such as those imposed by the current tax code. The distortions introduced by existing taxes, in combination with new regulatory requirements, are collectively referred to as the tax-interaction effect. One of the major conclusions of this emerging literature is that the social cost of environmental policy changes can be substantially higher when pre-existing tax distortions are taken into account. Our direct cost estimates do not reflect quantification of this effect, in part because of the emerging nature of this literature and in part because existing estimates of the magnitude of the tax-interaction effect are calculated as increments to social costs and are not necessarily applicable adjustments to direct cost estimates.

[9] Estimates are in 1990 dollars. The retrospective states, "In general the estimated second order macroeconomic effects were small relative to the size of the U.S. economy." The rate of long term GNP growth between the control and no-control scenarios amounted to roughly one-twentieth of one percent less growth.

[10] See, for example, Harrington *et al* (1999), referenced in Appendix B, for a comparative analysis of ex ante and ex post regulatory cost estimates.

- Fourth, undertaking a general equilibrium modeling exercise remains a very resource-intensive task. For the purposes of comparing costs to benefits we concluded that more detailed modeling would not be the most cost-effective use of the project resources.

Uncertainty in the Cost Estimates

Overview

As we note at the beginning of this chapter, explicit and implicit assumptions regarding changes in consumption patterns, input costs, and technological innovation are crucial to framing the question of the CAAA's cost impact. Given the nature of this prospective study, there is no way to verify the accuracy of the assumptions applied to future scenarios. We can envision other plausible analyses with estimates that differ from results in this chapter. Moreover, for many of the factors contributing to uncertainty, the degree or even direction of the bias is unknown or cannot be determined. Nevertheless, uncertainties and/or sensitivities can be identified and in many cases the potential measurement errors can be quantitatively characterized. In this section of the chapter, we first discuss several quantitative sensitivity analyses undertaken to characterize the impact of key assumptions on the ultimate cost analysis. We conclude the chapter with a qualitative discussion of the impact of both quantified and unquantified sources of uncertainty.

Quantitative Sensitivity Tests

In order to characterize the uncertainty in the cost estimates, we conducted sensitivity analyses on the key parameters and analytic assumptions of six major provisions. The provisions are the following:

- Progress Requirements,
- California Reformulated Gasoline,
- PM NAAQS Controls,
- LEV program (the National and California programs combined),
- Non-utility Stationary Source NO_x Controls, and
- NO_x Tailpipe/Extended Useful Life Standard.

We selected these provisions because they are among the most significant sources of CAAA costs, yet cost estimates for each of the provisions incorporate significant uncertainties. Collectively, these provisions account for nearly 50 percent of total direct compliance cost estimates for 2010. Table 3-2 summarizes the methods we used to conduct the cost sensitivity analyses and the results.

For each test, we developed three estimates for one or more components of costs affecting the total cost estimate for a given provision: (1) a central estimate, equal to the 2010 primary cost estimate reported in this chapter[11], (2) a low estimate; and (3) a high estimate. The low and high estimates assess the potential magnitude of the effect of the component(s) on the provision's costs and consequently, total CAAA costs, using reasonable alternative assumptions for each cost component. For progress requirements, PM NAAQS controls, and stationary source NO_x controls, the cost projections are based on models of future emissions controls. Accurately identifying the set of adopted controls is a key source of uncertainty. For example, cost-effective control measures for complying with progress requirements have not yet been identified and the sensitivity test suggests the potential for substantial variability in progress requirement compliance costs. In the case of motor vehicle provisions, there are two significant sources of uncertainty, projecting future car sales and forecasting accurate per vehicle costs.

The results indicate that the sensitivity of our primary cost estimates (central estimates) is not uniform across provisions. In addition, low and high estimates may vary by as much as a factor of two. These sensitivity analyses demonstrate the potential effect of altering selected assumptions and data. We do not assign probabilities to the likelihood of the alternative. In other words, it would be inappropriate simply to add up the array of low and high estimates to arrive at an overall range of uncertainty around the central estimates, because it is unlikely that a plausible scenario could be constructed where all the estimates are concurrently either at the high

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[11] The one exception is the central estimate of progress requirements. Our sensitivity analysis which is based on more recent cost information indicates that our primary estimate is more reflective of a high estimate. See Appendix B for more details.

or low end of their individual plausible ranges. A better interpretation of these results is that uncertainty in key input parameters can have a significant effect on the overall uncertainty of our estimates of direct compliance costs and ultimately the net benefits calculation.

In addition to examining specific provisions, we conducted a sensitivity analysis of the cost of capital used throughout the analysis. Cost estimates presented earlier in this chapter reflect application of a cost of capital (for the purposes of annualizing total capital costs) of five percent. We also examined the effect on cost estimates for those provisions which involve significant capital expenditures and where we could recalculate annualized costs from the available information. These provisions include non-utility and area source estimates for VOC, NO_x, and PM control. The alternative estimates use three and seven percent for the cost of capital. Results indicate that cost estimates are only moderately sensitive to the discount rate. The provisions evaluated have a total annualized capital cost of approximately $3 billion in 2010. Varying the cost of capital generated alternative estimates of $2.8 billion (three percent) and $3.1 billion (seven percent).[12]

Qualitative Analysis of Key Factors Contributing to Uncertainty

There are a wide range of other factors which contribute to uncertainty in the overall cost estimates. In most cases, the effect of these other factors cannot be quantitified, though some may have significant influences on our overall net benefits estimate. We present a summary of these factors in Table 3-3 below, and provide a characterization of the potential effect of each uncertainty on the primary estimate of the net benefits (i.e., if costs are overestimated, net benefits are underestimated). The two most important factors are the potential impact of innovation on the ultimate control costs incurred and the conservative assumptions we made to estimate RFP costs.

The regulatory documents which provide cost inputs to ERCAM and the IPM contain the most recent data available, given existing technological development. Between 2000 and 2010, however, advancements in control technologies will allow sources to comply with CAAA requirements at lower costs. For example, we anticipate technological improvements for complying with the multiple tiers of proposed emission standards during the phase-in of nonroad engine controls will likely lead to reduced costs. In addition, the costs for certain control equipment may decrease over time as demand increases and technology innovation and competition exert downward pressure on equipment prices. For instance, selective catalytic reduction (SCR) costs have decreased over the past three years as more facilities begin to apply the technology. We also believe that even in the absence of new emission standards, manufacturers will eventually upgrade engines to improve performance or to control emissions more cost-effectively; firms will institute technologies such as turbocharging, aftercooling, and variable-valve timing, all of which improve engine performance.

There is considerable uncertainty surrounding the development of States' control plans for meeting ozone NAAQS attainment requirements. We base the RFP cost estimate on the assumption that ozone nonattainment areas (NAAs) will take credit for NO_x reductions for meeting progress requirements. Additional area-specific analysis would be necessary to determine the extent to which areas find NO_x reductions beneficial in meeting attainment and progress requirement targets. Trading of NO_x for VOC to meet RFP requirements may result in distributions of VOC and NO_x emission reductions which differ from those used in this analysis. In response to these uncertainties, we adopted a conservative strategy for estimating the costs of RFP reductions in the primary analysis. We use a relatively high cost per ton reduced estimate of $10,000 for all required reductions. Since the time we conducted our primary cost analysis more information has emerged suggesting controls could cost much less, perhaps as little as $3,500 (see Table 3-2 and Appendix B for more details). In our sensitivity analysis of this variable, we incorporate the more recent cost per ton estimates. The analysis suggests that the $10,000 per ton reduced may in fact be more repre-

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[12] Note that these calculations reflect the use of alternative discount rates to estimate annual costs. The use of alternative rates to calculate the total net present value of costs incurred through the full 1990 to 2010 study period is examined separately in Chapter 8, where we compare total costs to total benefits.

Table 3-2
Results of Quantitative Sensitivity Tests

Provision	Primary Cost Estimate in 2010[1] (billions 1990 $)	Strategy for Sensitivity Analysis	Range of Estimates from Sensitivity Test (billions 1990 $)
Progress Requirements	$2.46	Vary unit costs for unidentified measures	$1.07 - $2.46 (central, $1.15)
California Reformulated Gasoline	$2.45	Vary incremental fuel costs and gasoline sales estimates	$1.4 - $3.5
PM NAAQS Controls	$2.22	Vary model attainment plan assumptions and cost per ton estimates	$0.09 to $3.35
LEV costs (California and National Combined)	$2.16	Vary per vehicle costs and projections of vehicle sales	$1.08 - $2.48
Non-Utility Stationary Source NO_x Costs	$2.15	Vary unit-level cost per ton	$1.1 - $3.2
NO_x Tailpipe/Useful Life Standards	$1.65	Vary per vehicle costs and vehicle sales data	$0.83 - $2.48

Note:
[1] In all cases, except progress requirements, the Post-CAAA 2010 primary cost estimates is equal to the central estimate in the sensitivity analysis. For more details on the sensitivity analysis of progress requirements and other provisions, see Appendix B.

sentative of an upper bound cost estimate, rather than a central estimate as our primary cost analysis reflects. The result of our conservative approach indicates that we may overstate RFP costs by a factor of two in 2010.

One other factor is also worth noting, although its impact is likely to be less important than the previous two factors. Under the 1990 CAAA, EPA created economic incentive provisions in several rules to provide flexibility for affected facilities that comply with the rules. These provisions include banking, trading, and emissions-averaging provisions. Flexible compliance provisions tend to lower the cost of compliance. For example, the emissions-averaging program grants flexibility to facilities affected by the marine vessels rule, the petroleum refinery National Emission Standard for Hazardous Air Pollutants (NESHAP), and the gasoline distribution NESHAP. These facilities can choose which sources to control, as long as they achieve the required overall emissions reduction. In many of the cost analyses, EPA does not attempt to quantify the effect that economic incentive provisions will have on the overall costs of a particular rule. In these cases, to the extent that affected sources use economic incentive provisions to minimize compliance costs, costs may be overstated. The major trading programs authorized under the Amendments, however, governing sulfur and nitrogen oxide emissions reductions from utilities and major non-utility point sources, are reflected in the cost estimates presented here.

Table 3-3
Key Uncertainties Associated with Cost Estimation

Potential Source of Error	Direction of Potential Bias for Net Benefits	Likely Significance Relative to Key Uncertainties on Net Benefits Estimate[1]
Costs are based on today's technologies. Innovations in future emission control technology and competition among equipment suppliers tend to reduce costs over time.	Underestimate	Probably minor. Available evidence suggests that estimates of pollution control costs based on current engineering can substantially overestimate the ultimate cost incurred, resulting in understating net benefits.[2]
Uncertainty of final State strategies for meeting Reasonable Further Progress (RFP) requirements.	Underestimate	Probably minor. We apply a conservative estimate for costs of RFP measures. Available evidence for identified RFP measures suggests costs could be as much as 70 percent lower than this value. The bias most likely results in significantly understating net benefits.
Errors in emission projections that form the basis of selecting control strategies and costs in both the IPM and ERCAM models.	Unable to determine based on current information	Probably minor. In many cases, emissions reductions are specified in the regulations, suggesting that errors in the estimation of absolute levels of emissions under Pre- and Post-CAAA scenarios may have only a small impact on cost estimates. The effect on net benefits is unknown.
Exclusion of the impact of economic incentive provisions, including banking, trading, and emissions averaging provisions.	Underestimate	Probably minor. Economic incentive provisions can substantially reduce costs, but the major economic programs for trading of sulfur and nitrogen dioxide emissions are reflected in the analysis.
Incomplete characterization of certain indirect costs, including vehicle owner opportunity costs associated with Inspection and Maintenance Programs and performance degradation issues associated with the incorporation of emission control technology.	Overestimate	Probably minor. Preliminary evidence suggests that the opportunity costs of vehicle owners is most likely small relative to other cost inputs.[3] In addition, it is will vary from State to State and is subject to a variety of influencing factors. The potential magnitude of indirect costs associated with performance degradation is more uncertain, because few data currently exist to quantify this effect.

Table 3-3 (continued)
Key Uncertainties Associated with Cost Estimation

Potential Source of Error	Direction of Potential Bias for Net Benefits	Likely Significance Relative to Key Uncertainties on Net Benefits Estimate[1]
Choice to model direct costs rather than social costs	Unable to determine based on current information	Probably minor. The relationship of social cost to direct cost estimates is influenced by multiple factors that operate in opposite directions, suggesting the magnitude of the net effect is reduced. Social cost estimates can reflect the net welfare changes across the full range of economic sectors in the U.S, and so may yield higher estimates of costs than a direct cost approach. In addition, social cost estimates can be constructed to reflect the potentially substantial cost-magnifying effect of existing tax distortions. Direct cost estimates, however, are likely to overstate costs in the primary market because they do not reflect consumer and producer responses. The extent to which a direct cost estimate will overstate or understate a social cost estimate depends on the magnitude of the "ripple effects" in economic sectors not targeted by a regulation. In addition, assessment of the effect on net benefit estimates must also account for any economy-wide effects of direct benefits (e.g., the broader implications of improving health status, and improving environmental quality).
Use of costs for rules that are currently in draft form (i.e., not yet finalized).	Unable to determine based on current information	Probably minor. Rules that are most important to the overall cost estimate are largely finalized. For example, there is some uncertainty as to how the cap-and-trade program through the SIP process will lower NOx emissions in an efficient manner. The expected effect on net benefits is minimal.
Exclusion of costs of 7-year and 10-year MACT standards and the residential risk standards for the 2- and 4-year MACT standards.	Unable to determine based on current information	Probably minor. Costs for the 7- and 10-year MACT standards are likely to be less than for the 2- and 4-year standards included in the analysis and the need for, and potential scope and stringency of, future Title III residual risk standards remain highly uncertain. For consistency, benefits of the 7- and 10-year standards and the residual risk standards are also excluded.

Note:

[1] The classification of each potential source of error reflects the best judgement of the section 812 Project Team. The Project Team assigns a classification of "potentially major" if a plausible alternative assumption or approach could influence the overall monetary benefit estimate by approximately five percent or more; if an alternative assumption or approach is likely to change the total benefit estimate by less than five percent, the Project Team assigns a classification of "probably minor."

[2] For more detail, see Harrington et al (1999), referenced in Appendix B.

[3] Preliminary evidence based on Arizona's Enhanced I/M program indicates that major components of the programs costs are associated with test and repair costs rather than the costs of waiting and travel for vehicle owners. (Harrington and McConnell, 1999.) To date, Enhanced I/M programs have been implemented in only four States.